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CONRAD WP5: COORDINATION OF RESEARCH ON INTERNAL DOSIMETRY

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CONRAD WP5: COORDINATION OF RESEARCH ON INTERNAL DOSIMETRY

ABSTRACT

The EUropean RAdiation DOSimetry Group, EURADOS, initiated in 2005 the CONRAD Project, a Coordinated Network for Radiation Dosimetry funded by the European Commission (EC), within the 6th Framework Programme (FP). The objective of CONRAD Work Package 5 is the coordination of research on the assessment of internal exposures. Twenty institutes from 14 countries participated in this action. The activities developed have contributed to improve the harmonisation and reliability in the assessment of internal doses. An internal dosimetry network has been generated to facilitate dissemination of knowledge and coordination of research.

WP5 tasks included a study of uncertainties and the refinement of the IDEAS Guidelines associated with the evaluation of doses after intake of radionuclides. The impact of the use of new biokinetic models for dose assessment and the first attempt to develop a dosimetric model for DTPA therapy are important WP5 achievements. New developments in voxel phantoms and Monte Carlo simulations for assessment of intakes from *in vivo* measurements were also considered. A Nuclear Emergency Monitoring Network has been established for the interpretation of monitoring data for emergency workers after accidental or deliberate releases of radionuclides. Finally, WP5 group has worked on the maintenance of the existing IDEAS bibliographic, internal contamination and case evaluation databases.

Some WP5 tasks were linked with ICRP activities, a joint-action was established with CONRAD Work Package 4 “Computational Dosimetry” and collaborations with other EC research projects (TMT-handbook, Tiara) and with relevant institutions such as DOE (USA) and CEA (France) were carried out for some specific activities. CONRAD achievements were disseminated through web sites, scientific publications, presentations to workshops and training activities. The last action of the group consists in the organisation of the EURADOS-IAEA Training Course “Application of IDEAS Guidelines and dissemination of CONRAD results”, at University of Prague on February 2009. Final results associated with CONRAD WP5 tasks are presented here.

CONRAD WP5: COORDINATION OF RESEARCH ON INTERNAL DOSIMETRY

CONTENTS

1.- INTRODUCTION

2.- MANAGEMENT OF CONRAD WP5

3.- COORDINATION OF RESEARCH

  3.1.- TASKS 5.1, 5.5: UNCERTAINTY STUDIES AND UPDATE OF IDEAS GUIDELINES AND DATABASES

  3.2.- TASK 5.2: RESEARCH STUDIES ON BIOKINETIC MODELS

    3.2.1.- TASK 5.2.1: DEVELOPMENT, IMPLEMENTATION AND QUALITY ASSURANCE OF BIOKINETIC MODELS

    3.2.2.- TASK 5.2.2: TOWARDS A BIOKINETIC MODEL FOR DTPA THERAPY

  3.3.- TASK 5.3: NEW DEVELOPMENTS ON MONTE CARLO APPLICATIONS TO IN-VIVO ASSESSMENT OF INTAKES

  3.4.- TASK 5.4: DEVELOPMENT OF AN EMERGENCY MONITORING NETWORK

4.- DISSEMINATION OF KNOWLEDGE: WEB SITES, WORKSHOPS, PUBLICATIONS, INTERCOMPARISONS, DATABASES AND TRAINING

5.- THE INTERNAL DOSIMETRY NETWORK

6.- CONCLUSIONS AND FUTURE ACTIONS

7.- APPENDIX A: CONRAD WP5 PUBLICATIONS

CONRAD WP5: Coordination of Research on Internal Dosimetry

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1 INTRODUCTION

The CONRAD (Coordinated Network for Radiation Dosimetry) Action, funded by the European Commission (EC) within the 6th Framework Programme (FP) for research and training in nuclear energy (Contract No FI6R-012684), was initiated in January 2005 and will be finished in May 2008. The partners of the project are EURADOS (www.eurados.org), Technical University of Delft (The Netherlands) and University of St. Gallen (Switzerland). The objectives of this action are (1) the analysis of the options for a sustainable European Network in the field of Radiation Dosimetry and (2) to coordinate research into measurements and calculations for radiation protection at workplaces to promote both, research activities and dissemination of knowledge. To achieve the stated objectives seven work packages (WP) were carried out.

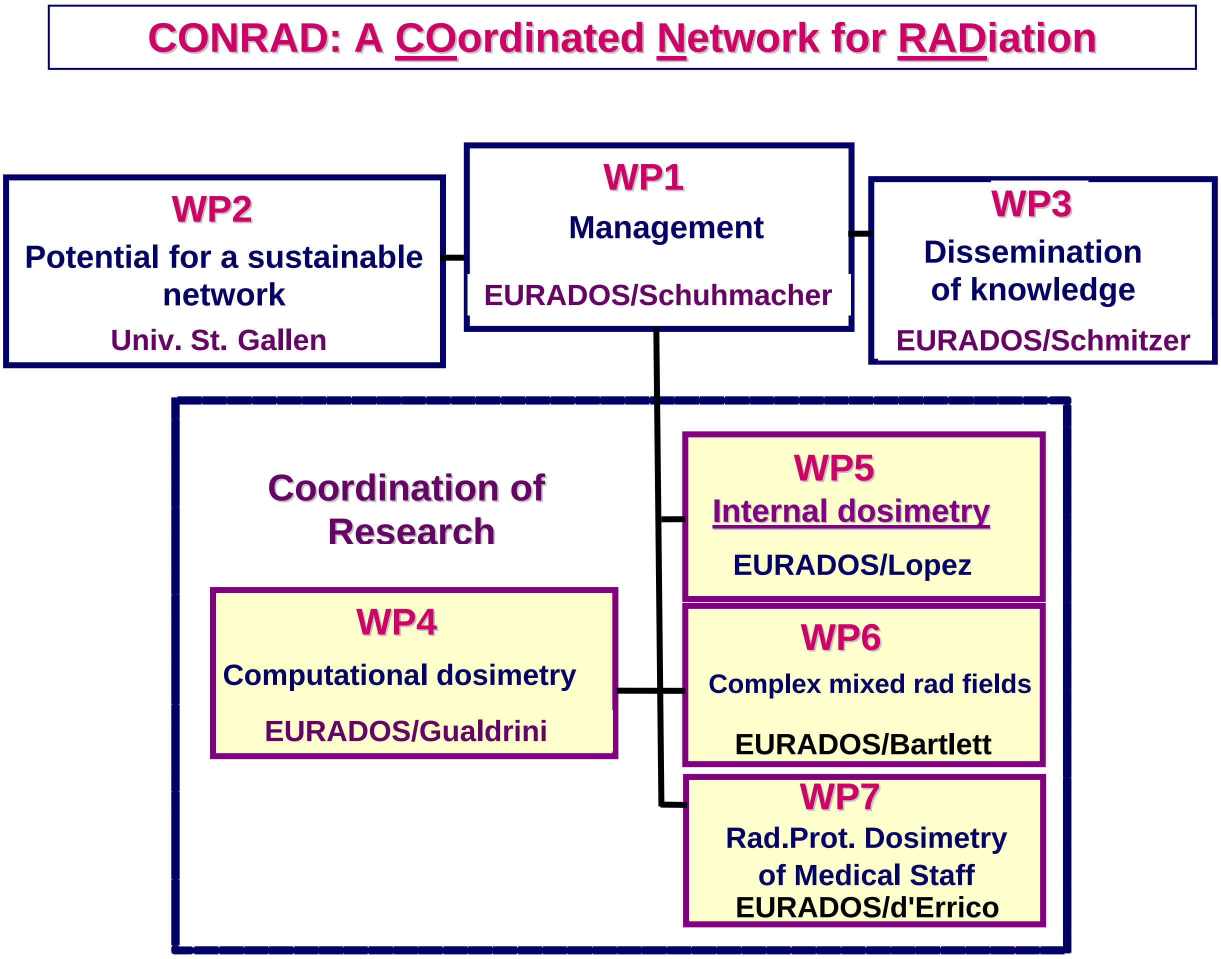

Figure 1.- The CONRAD Project

Work package 5 (WP5) within CONRAD has dealt with the Coordination of Research on Internal Dosimetry. The research to be coordinated had as general objective to improve the reliability in the assessment of exposures resulting from the intake of radionuclides into the body.

Internal Dosimetry embodies always a challenge. Internal doses can not be measured directly, each chemical compound behaves differently inside the body, the distribution of the activity in is highly inhomogeneous, and doses are prolonged in time. Research in this area is a highly specialised undertaking involving physicists at various European institutions. Progress is made more efficient by active co-operation between scientists working in the field.

The last EURADOS study on individual monitoring for internal exposures in Europe(1) and recent international intercomparisons on dose assessments(2) have revealed that different laboratories can obtain different estimates of intakes and doses when provided with the same monitoring data. The harmonisation in the implementation of adequate internal dose assessment criteria and methodology is an important goal to achieve.

Doses from intakes of radionuclides must be assessed from monitoring data using direct (whole/partial body counting) or indirect techniques (in-vitro methods and PAS/SAS). The assessment of internal doses requires the application of biokinetic models (describing the metabolic behaviour of the radionuclide inside the body) and input parameters such as time and route of intake and material properties (size of particles, absorption type). Even if all this information is correct, the result of the assessment of the committed effective dose E(50) depends on the skill of the assessor and the hardware/software tools available.

IDEAS Guidelines(3) have been developed to provide a standard assessment of intakes and internal doses from individual monitoring data. The aim of this methodology is to guarantee a harmonised evaluation of internal exposures, in such way that (1) two assessors following guidelines would obtain the same estimate of dose from an individual monitoring data set and (2) the “best estimate” of E(50) is achieved. IDEAS Guidelines were generated in collaboration with Committee 2 of the International Commission on Radiological Protection (ICRP). ICRP provides and regularly updates the biokinetic models, retention/excretion functions and dose coefficients needed for the evaluation of intakes and doses from monitoring data.

The scenario presented above was the framework to initiate the CONRAD action. Work Package 5(4) was clearly focused towards harmonisation and coordination of research on internal dosimetry.

The study of uncertainties associated with the assessment of internal exposures and the refinement of the IDEAS general guidelines for internal dose estimate from monitoring data have contributed to a more harmonised and accurate assessment of intakes and Committed Effective Doses E(50).

The impact of the application of new biokinetic models for dose assessment has been evaluated; special interest was put on the new ICRP Human Alimentary Tract Model (HATM), new systemic models and the new NCRP Wound Model. These results are important as a support for on-going efforts of the ICRP Committee 2 Task Group on Dose Calculation (DOCAL), as well as for the recently initiated process of review of the IAEA Basic Safety Standards.

The first attempt to develop a dosimetric model for the interpretation of monitoring data affected by DTPA therapy was performed within CONRAD WP5. A very successful collaboration with CEA (Commissionat de la Énergie Atomique, France) and Tiara (EC research Project) members was established. This activity is not finalized yet and will continue in the future.

The new developments in the use of voxel phantoms and Monte Carlo applications for the assessment of intakes from in-vivo measurements have been evaluated. A joint action was established with CONRAD WP4-Computational Dosimetry in relation to the organisation of an “Intercomparison on Monte Carlo modelling for in vivo measurements of Americium in a knee phantom”. A selected group of laboratories have been involved in a CONRAD-DOE (USA) collaboration, to work with the USTUR leg phantom, which contain a real bone contaminated with americium coming from the body of a contaminated person

A European Emergency Network (EUREMON) has been established to coordinate procedures and methodologies to be applied for the interpretation of monitoring data for emergency workers after accidental or deliberate releases of radionuclides (e.g. nuclear terrorism). A collaboration with EC research project TMT-handbook was carried out.

Finally, the WP5 group has worked on the maintenance and update with new cases of existing IDEAS bibliographic, internal contamination and case evaluation databases.

CONRAD achievements were disseminated through web sites, scientific publications, presentations to workshops and training activities. The EURADOS/CONRAD WP5 web site (www.eurados.org) summarises the objectives and activities proposed in this action, and includes the links of ENEA/Ideas (www.bologna.enea.it/attivita/ideas.html/) and SCK/Ideas web pages (www.sckcen.be/ideas/).

The last action of the group consists in the organisation of the EURADOS-IAEA Training Course “Application of IDEAS Guidelines and dissemination of CONRAD results”, at University of Prague on February 2009.

Final results associated with CONRAD WP5 tasks are presented here.

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2 MANAGEMENT OF CONRAD WP5

2.1.- WP5 OBJECTIVE

The aim of CONRAD Work Package 5 (WP5) is to promote the coordination of research and the dissemination of knowledge in the field of internal dosimetry. The research to be coordinated will improve the reliability in the assessment of internal doses. Forty scientists (15 full CONRAD members, 25 corresponding members) from 20 institutes and 14 countries participate in this working group; CIEMAT (Spain) is the institution chairing this action.

2.2.- WP5 WORKPLAN

The Plan of Work of CONRAD WP5 was established according 5 main tasks, performed by subgroups of WP5 members, managed by task-group coordinators:

Task 5.1.- Assessment of internal exposures:

- **Task T5.1.1** - **Uncertainty studies**.
  Coordinator: **J.W. Marsh, HPA, UK**

The aim of this task is to evaluate uncertainties in intakes and doses assessed from monitoring data. The work programme included (a) the calculation of measurement uncertainties (i.e. Scattering Factors), (b) the development of codes to assess the uncertainties in the intake and dose and (c) the performance of uncertainty analysis studies.

The Scattering Factors (SF) are used to characterise the uncertainty of monitoring data used in the evaluation of intakes and internal doses. The values provided by IDEAS Guidelines were mainly defined by expert's judgement. The calculation of SF for some cases of interest selected from IDEAS Databases, was an important activity to carry out by this task-group. Scattering Factors have been considered in the Uncertainty study of dose assessment within the ISO Standard 27048 "Dose assessment for the monitoring of workers for internal radiation exposure". This matter is important because shows an agreement, thus, harmonisation, in the approaches for the characterization of uncertainties in measured bioassay quantities, in both reference documents (IDEAS Guidelines, ISO standard) for the assessment of internal doses.

Software had to be developed for the study of uncertainties involved in the evaluation of internal doses. IRSN classical (frequentist) approach and HPA Bayesian approach (calculation of the conditional probability distribution of the intake or dose given the measurement data) were considered. A comparison of the uncertainties calculated by both approaches was carried out for the case of inhalation of tritiated water (HTO). Intake pattern assumptions were evaluated, comparing (1) ICRP recommendation of intake occurring at the mid-point of the monitoring period and (2) assumption of constant chronic intake throughout the monitoring interval.

- Task 5.1.2. Improvement of IDEAS Guidelines
Coordinator: **C.M. Castellani, ENEA, Italy**

An update of IDEAS Guidelines and the generation of a new IDEAS web page as information forum for the dissemination of knowledge among the dosimetry community were the main objectives of this task group.

With reference to the refinement of the IDEAS Guidelines (GLs), Report FZKA7243 (July 2006) will be updated including CONRAD results. The conclusions of the Scattering Factors study of CONRAD Task T5.1.1 will improve the IDEAS GLs in some specific cases. Flow charts to use in case of wound contamination have been provided. A common work with Task T5.2 group was carried out dealing with the implementation of NCRP wound model and the use of a partitioning factor of the activity between skeleton and liver to be used in fitting systemic model parameters for actinides. Evaluations of wound contamination have been done with the application of IDEAS GLs philosophy.

Other tasks performed by the IDEAS group were the study of Effective AMAD evaluation and the criteria to be applied (number and type of data) as requirements for assessment of doses.

The IDEAS/ENEA web site (www.bologna.enea.it/attivita/ideas.html) replaces the former IDEAS web page. As application of GLs, the results of the IDEAS/IAEA Intercomparison exercise on Internal Dose Assessments can be downloaded from this site, as well as other important reports and documents related to IDEAS, CONRAD and ICRP activities.

A Training Course on “Application of IDEAS Guidelines and dissemination of CONRAD results” will be organized at the end of CONRAD Project. Carlo Maria Castellani (ENEA, Italy) is the coordinator of the event and the University of Prague (contact person: Tomas Vrba) will be the institute to host the course. This training activity will be organized as a joint EURADOS-IAEA action by February 2009.

Task T5.2.- Research studies on biokinetic models
Coordinator: **D. Nosske, BfS, Germany**

The impact of the application of new models for dose assessment was evaluated. The implementation of the Human Alimentary Tract Model, NCRP Wound Model and systemic models, including QA of implementation and model formulation are the main goals of this task, together with stable isotope studies and the modelling of the effects of DTPA treatment.

- Task 5.2.1.- Development, implementation and quality assurance of biokinetic models

Coordinator: **D. Nosske, BfS, Germany**

With reference to the implementation of the new ICRP Human Alimentary Tract Model (HATM) an intercomparison of number of transformations and faecal excretion rates of various radionuclides including daughter nuclides as well as retention in the walls of the tract and absorption from different sites was proposed and implemented in 5 codes. Calculations considering recycling model were carried out.

The new NCRP Wound model (likely future ICRP Wound Model) was implemented into 6 codes for calculations; the 7 default categories of wound retention were considered.

Concerning the studies of Systemic Models, a comparison of three systemic Plutonium models was carried out by calculating the numbers of nuclear transformations for the ICRP 67 model, the Leggett 2005 model and the Luciani (age-dependent) model. In the application of biokinetic models for Plutonium and other actinides, the partitioning factor was evaluated as parameter to characterise the partitioning between liver and skeleton. A comparison of the implementation of the new ICRP Polonium model was also considered.

A relevant and successful activity included in this work area is the experimental studies with stable isotopes carried out by Helmholtz Zentrum München, in collaboration with the University of Milan. These involve isotopes of Sr, Mo, Zr, Ru, and Ce that were administered intravenously and orally to volunteers. Results of absorption to HAT, blood clearance and urinary excretion were analysed.

- Task 5.2.2.- Towards a DTPA-Therapy Model

Coordinators: **B. Breustedt, FZK (Germany),**
E. Blanchardon, IRSN (France)

The development of a preliminary model considering the effects of DTPA Treatment was the main aim of this DTPA-decorporation group. The therapy with DTPA (Diethylene Triamina Pentaacetic Acid) is applied in case of severe internal contamination with Plutonium. The effect of DTPA treatment is the enhancement of urinary excretion of Plutonium, thus, the reduction of internal doses. A reliable modelling decorporation is needed for interpretation of bioassay data using the best physiologic models to describe the systemic behavior of internal contaminants as Plutonium (Pu) inside the body.

This task was begun at the mid-term of the CONRAD action. The objective to achieve is a proposal of a model structure, with initial parameters for the implementation of the model. The test of the proposed model with real data and iterative improvement of the model are steps to carry out. International collaboration outside CONRAD was established with experts from CEA (France) and FZK-Karlsruhe (Germany), also involved in DTPA research studies.

Task T5.3.- New developments on Monte Carlo applications to in-vivo assessment of intakes

Coordinator: **D. Franck, IRSN, France**

The objective of this task is to take advantage of the innovative approaches developed for the creation and application of voxel phantoms and Monte Carlo (MC) methods for the calculation of calibration factors for whole body counting systems. In this framework a collaboration with CONRAD WP4-Computational Dosimetry was established and a joint CONRAD-DOE action was carried out. Final objectives are the comparison of MC codes and the evaluation of the capability of laboratories to deal with such type of exercises.

The Intercomparison on Monte Carlo modelling for in vivo measurements of Americium in a knee phantom was organized as joint CONRAD WP4-WP5 action. The exercise (available at EURADOS web site www.eurados.org) was distributed by e-mail in February 2006 to the laboratories that expressed interested in participating. Results were received from 13 participants (15 answers) of 11 countries by the end of November 2006.

A voxel phantom was generated at CIEMAT from the CT-images of a real knee phantom used for calibration purposes. A counting geometry using 2 LE Ge detectors was proposed. Counting efficiency results obtained by Monte Carlo simulations by the 13 participants of the Intercomparison exercise, were compared with the experimental efficiency value for ^{241}Am (using photopeak of 59.5 keV) obtained through the measurement of the active Spitz calibration knee-phantom at the CIEMAT Whole Body Counting facility. The objective is to confirm MC methods and the voxel phantoms as valuable tools for the calculation of in-vivo calibration factors, to be applied for the assessment of intakes and internal doses. The results of the Intercomparison were presented at the Workshop on Computational Dosimetry "Uncertainty Assessment in Computational Dosimetry organised by Gianfranco Gualdrini in ENEA (Bologna, Italy) in October 2007.

A joint action has been established with DOE (Department of Energy, USA) to collaborate in an in-vivo monitoring and MC modelling exercise for the determination of the Am-241 deposited in the USTUR (United States Transuranium and Uranium Registry) knee phantom, containing real contaminated bone from a real internal contamination. A protocol has been proposed, and a small group of selected laboratories from Europe (CIEMAT, IRSN, Helmholtz Zentrum München) and America (HML-Canada, PNL-USA) participated in the exercise. The studies to focus on are: (1) the efficiency pattern along the leg phantom (experimental and computational) and (2) the influence of Americium distribution in the bone material (volume or surface).

Task T5.4.- Interpretation of monitoring data after accidental or deliberate releases of radionuclides

Coordinator: **G.Etherington, HPA, UK**

The aims of this monitoring in emergency task are (a) the development of a network of people with responsibilities for emergency monitoring of people; (b) sharing of information on monitoring and dose assessment procedures; (c) sharing of information on research and development (R&D); (d) coordination of this work; and (e) definition of needs for research, advice and training.

The focus of this group was the establishment of the EUREMON Network (EURopean Emergency MONitoring network). Fifty European members from 21 EU countries 9 non-EU states and IAEA participate in the Network.

The compilation of information is carried out through the distribution of a questionnaire, prepared in collaboration with EC 6FP project TMT HANDBOOK. The objective is collecting relevant information of interest concerning organisations, legislation, monitoring strategies, equipments and facilities for individual monitoring, medical management, dose assessment methodologies and available software in case of emergency situations with release of radioactive material. The EUREMON Access Database is constructed with all the data collected.

An important activity of this task-group is the compilation of information about portable and transportable monitoring equipment available in each European state in case of nuclear emergency situation. This information could be used by countries requiring assistance in responding to a nuclear emergency. The compilation will be published together with contact details for requests for assistance.

Task T5.5.- Update of IDEAS Databases

Coordinator: **C. Hurtgen, SCK_CEN, Belgium**

The IDEAS Bibliography Database contains a collection of publications with information on cases of internal contamination from which intake and committed doses could be assessed. The IDEAS Internal Contamination Database consists of published internal contamination cases with monitoring data suitable for dose assessment; IDEAS guidelines were applicable to a wide range of practical situations. The “Evaluation of Cases Database” contains a summary of information about the evaluations of some 47 cases taken out of the previous database.

As the CONRAD project proceeds, IDEAS Bibliography and IDEAS Internal Contamination Databases were updated with new inputs. All three IDEAS databases are now available to the internal dosimetry community on SCK·CEN website (www.sckcen.be/ideas/) and IDEAS/ENEA webpage.

The activities developed by each Task group are described by the task-coordinators ahead in this document

2.3.- WP5 DELIVERABLES

The deliverables associated to WP5 consist in the Final Reports of the activities developed as coordination of Research, and the Updated Internal Dosimetry Databases. All the deliverables will be available on Month 38 (February 2008).

Task	**Start date**	**Final date**	**Deliverable**
T5.1.- Assessment of internal exposures: T5.1.1- Uncertainties study T5.1.2.- IDEAS guidelines	Apr-05	Feb-08	Report on uncertainties and improvement of the IDEAS guidelines
T5.2.- Research studies on biokinetic models T5.2.1- Implementation and QA of biokinetic models T5.2.2.- DTPA-therapy Model	Apr-05	Feb-08	Report on the applicability of models for dose assessment
T5.3.- New developments in Monte-Carlo applications for in-vivo assessment of intakes (coordination with WP4)	Apr-05	Feb-08	Reports on new developments of Monte Carlo applications and on the benchmark exercise
T5.4.- Interpretation of monitoring data after accidental or deliberate releases	Apr-05	Feb-08	Report on the interpretation of monitoring data after accidental or deliberate releases of radionuclides
T5.5- Internal contamination databases	Apr-05	Feb-08	Updated Internal Dosimetry Databases

2.4.- WP5 BUDGET

WP5	**2005**	**2006**	**2007**	**2008**	**Total**
Person-power	2021	0	0	0	2021
Travel	200	7755	11356	10000	28311
Total:	**2221**	**7575**	**11356**	**10000**	**40332**

2.5.- WP5 MEMBERS: 15 FULL (F); 25 CORRESPONDING (C) MEMBERS

Function	***Name***	***Institute***	***F/C Member***
Chairperson	Maria Antonia Lopez	CIEMAT (Spain)	F
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T5.1.2 Coordinator	Carlo Maria Castellani	ENEA (Italy)	F
T5.2 Coordinator	Dietmar Nosske	BfS (Germany)	F
T5.2.2 Coordinator	Eric Blanchardon	IRSN (France)	F
T5.2.2 Coordinator	Bastian Breustedt	FZ Karlsruhe	C
T5.3 Coordinator	Didier Franck	IRSN (France)	F
T5.4 Coordinator	George Etherington	HPA (UK)	F
T5.5 Coordinator	Christian Hurtgen	SCK-CEN (Belgium)	F
T5.1, T5.3	Hans Doerfel	Info-IDEA (Germany)	F
T5.1, T5.5	Andor Andrasi	AEKI (Hungary)	F
T5.1, T5.2	Andrea Luciani	ENEA (Italy)	F
T5.1, T5.2	V.Berkowski/Y.Bonchuk/H.Ratia	RPI (Ukraine)	F
T5.1	Virginia Koukouliou	GAEC (Greece)	F
T5.2	Augusto Giussani	GSF (Germany)	F
T5.4	Tua Rahola	STUK (Finland)	F
T5.2	Uwe Oeh	GsF (Germany)	C
T5.1, T5.2, T5.5	Mike Bailey	HPA (UK)	C
T5.1, T5.2	Alan Birchall	HPA (UK)	C
T5.1, T5.2	Martin Puncher / J. Smith	HPA (UK)	C
T5.4	Alan Hodgson / N. Stradling	HPA (UK)	C
T5.4	Cécile Challeton de Vathaire	IRSN (France)	C
T5.3	David Broggio	IRSN (France	C
T5.2	Jean-René Jourdain	IRSN (France)	C
T5.1	Andrey Molokanov	IRSN (France)	C
T5.1	Irena Malatova	NRPI (Czech Rep)	C
T5.1	Tomas Vrba	NRPI (Czech Rep)	C
T5.4	Maarit Muikku	STUK (Finland)	C
T5.4	Paolo Battisti	ENEA (Italy)	C
T5.3	Montse Moraleda	CIEMAT (Spain)	C
T5.3	Gary H. Kramer	HML (Canada)	C
IAEA	Rodolfo Cruz	IAEA	C
T5.2	Imre Balashazy	AEKI (Hungary)	C
T5.2	Marie Claire Cantone	Univ. Milano (Italy)	C
T5.4	Philippe Bérard	CEA (France)	C
T5.4	Bernard Le Guen	EDF (France)	C

2.6.- WP5 MEETINGS

Date	**Location**	**WP5 meeting**
January 2005	Krakow, Poland	WP5 Core-group meeting
April 2005	Vienna, Austria	Meeting of WP5 group
June 2005 October 2005	Paris, France Madrid, Spain	Meeting of T5.3 (WP5) + WP4 group: Monte Carlo/In-vivo Intercomparison meetings
January 2005 May - 2005	Oxford, UK Madrid. Spain	WP5 Meeting; subgroup meetings at HPA IDEAS-CONRAD meeting at CIEMAT
October 2006	Montpellier, France	WP5 subgroup meetings
January 2007	Madrid, Spain	WP5 Meeting; subgroup meetings
May 2007	FZK, Germany	Task T5.2 (DTPA Model) Meeting
October 2007	Athens, Greece	WP5 Meeting; subgroup meetings
January 2008	Paris, France	WP5 Meeting; subgroup meetings
March 2008	Munich, Germany	EURADOS/CONRAD-IAEA Training Course Meeting
February 2009	Prague, Czech Rep.	EURADOS/CONRAD-IAEA Training Course

3 CONRAD WP5: COORDINATION OF RESEARCH

3.1. CONRAD TASKS 5.1, 5.5: UNCERTAINTY STUDIES AND UPDATE OF IDEAS GUIDELINES AND DATABASES

3.2. CONRAD TASK 5.2: RESEARCH STUDIES ON BIOKINETIC MODELS

3.2.1.- CONRAD TASK 5.2.1.- DEVELOPMENT, IMPLEMENTATION AND QUALITY ASSURANCE OF BIOKINETIC MODELS

3.2.2.- CONRAD TASK 5.2.2.- TOWARDS A BIOKINETIC MODEL FOR DTPA THERAPY

3.3. CONRAD TASK 5.3: NEW DEVELOPMENTS ON MONTE CARLO APPLICATIONS TO IN-VIVO ASSESSMENT OF INTAKES

3.4. CONRAD TASK 5.4: DEVELOPMENT OF AN EMERGENCY MONITORING NETWORK

3.1.- CONRAD TASKS 5.1 & 5.5: UNCERTAINTY STUDIES, UPDATE OF IDEAS GUIDELINES AND DATABASES.

Coordinator of Task T5.1.1: James Marsh (HPA, UK)
Coordinator of Task T5.1.2: Carlo Maria Castellani (ENEA, Italy)
Coordinator of Task T5.5: Christian Hurtgen (SCK-CEN, Belgium)

DELIVERABLE 5.1 - FINAL REPORT, FEBRUARY 2008 -

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3.1.- CONRAD TASKS 5.1 & 5.5: UNCERTAINTY STUDIES, UPDATE OF IDEAS GUIDELINES AND DATABASES

ABSTRACT

The work of Task Group 5.1 (Uncertainty studies and revision of IDEAS Guidelines) and Task Group 5.5 (update of IDEAS databases) of the CONRAD project is described. Scattering factor values (i.e. measurement uncertainties) have been calculated for different radionuclides and types of monitoring data using real data contained in the IDEAS Internal Contamination Database. Based upon this work and other published values, default SF values are suggested. Uncertainty studies have been carried out using both a Bayesian approach as well as a frequentist (classical) approach. The IDEAS Guidelines have been revised in areas relating to the evaluation of an effective AMAD, guidance on evaluating wound cases with the NCRP wound model and in aspects of data handling where the number and type of measurements required for dose assessment are suggested. Typical values for the lower limit of detection (LLD) have also been given for *in-vivo* and *in-vitro* measurements. The IDEAS Databases have been updated, in particular, additional cases have been added to the IDEAS Internal Contamination Database, so that it now contains more than 240 cases.

3.1.- CONRAD TASKS 5.1 & 5.5: UNCERTAINTY STUDIES, UPDATE OF IDEAS GUIDELINES AND DATABASES

CONTENTS

1 Introduction 27
2 Evaluation of measurement uncertainties for internal dose assessment 28
  2.1 Introduction... 28
  2.2 Procedure 29
  2.3 Results 32
  2.4 Discussion of results 32
  2.5 Suggested SF values for various types of measurement.......................... 34
  2.6 Conclusions on SF values 35
3 Uncertainty studies.. 35
  3.1 Frequentist approach 36
  3.2 Bayesian approach.. 37
  3.3 Tritiated water (HTO) example 37
  3.4 Application of Bayesian approach to the HTO example. 38
  3.5 Application of frequentist approach to the HTO example. 39
  3.6 Intake pattern assumptions 41
  3.7 Future work 42
  3.8 Conclusions on uncertainty studies 42
4 ENEA/ IDEAS web page 43
  4.1 Introduction... 43
  4.2 Structure of the IDEAS Project 43
  4.3 Future actions after the IDEAS project 47
  4.4 Preprints related to IDEAS activities 49
  4.5 Further actions 50
  4.6 Conclusions on web page 51
5 Effective AMAD evaluation.. 51
  5.1 Introduction... 51
  5.2 Methodologies 52
  5.3 Results 53
  5.4 Polynomial fitting of the data 56
6 Guidelines for the application of NCRP wound model 59
  6.1 Introduction... 59
  6.2 Application of the wound model to plutonium cases. 64
  6.3 Special procedure for wound cases. 74
7 Aspects of data handling 81
  7.1 Number and type of data required for assessment of dose....................... 81
  7.2 Lower limit of detection (LLD) values 82
8 IDEAS databases... 85
9 Conclusions.. 87
10 REFERENCES.. 88

1 INTRODUCTION

In this document the work of Task Groups 5.1 and 5.5 of the concerted action "A Coordinated Network for Radiation Dosimetry" (CONRAD)(1) is presented. This project started in April 2005 and ended in February 2008, and is funded within the EURATOM 6th Framework Programme for research and training in nuclear energy (contract No FI6R-012684). It involves two main activities to maintain and enhance competence in radiation protection dosimetry: It analyses the options for sustainable networks linking research players and end users and it coordinates research on measurements and calculations for radiation protection at workplaces.

CONRAD is structured into 7 workpackages. Work package 5, headed by Maria Antonia Lopez (CIEMAT, Spain), is dedicated to internal dosimetry(1). This workpackage is sub-divided into 5 Task Groups. Task Group 5.1 covers uncertainty studies and the revision of the IDEAS Guidelines(2). Eighteen scientists out of 10 European countries were working within this Task Group, jointly coordinated by Carlo Maria Castellani (ENEA, Italy) and James Marsh (HPA, UK). Task Group 5.5 deals with the update of the IDEAS internal contination database(3) and this task group is headed by Christian Hurtgen (SCK·CEN, Belgian).

The main areas of work that are described in this document are:

- Evaluation of measurement uncertainties for internal dose assessment.
- Uncertainty studies that estimate the uncertainty on the intake assessed from bioassay data. Two approaches were considered, namely the frequentist (classical) approach and the Bayesian approach.
- Design and development of a website for the IDEAS Guidelines and for the work of the CONRAD Tasks Groups 5.1 and 5.5.
- Evaluation of the effective AMAD (activity medium aerodynamic diameter).
- Application of the NCRP (National Council on Radiation Protection & Measurements) wound model. The model was applied to seven cases from the internal contamination database. Based on these cases and discussions within the group, guidelines for 'special procedures for wound cases' were developed. This procedure is only a starting point and is open for further discussion.
- Aspects of data handling, where the number and type of data required for dose assessment are given. Also typical values for the lower limit of detection (LLD) have been given for *in-vivo* and *in-vitro* measurements.
- IDEAS Databases. In particular, additional cases have been added to the IDEAS Internal Contamination Database, so that it now contains 255 cases.

2 EVALUATION OF MEASUREMENT UNCERTAINTIES FOR INTERNAL DOSE ASSESSMENT

2.1 Introduction

The recently developed guidelines(2) for the assessment of internal doses from monitoring data (IDEAS Guidelines) suggest default measurement uncertainties (i.e. scattering factors, SF) to be used for different types of monitoring data. Realistic SF values are important because:

- They are needed to assess the uncertainty in the estimated intake and dose.
- They determine the relative weighting of data in fitting process and can affect the estimated intake when different types of monitoring data are used simultaneously.
- They enable rogue data to be identified objectively.
- They enable objective (statistical) criteria (goodness-of-fit) to be calculated, which are used to determine whether the predictions of the biokinetic model (with a given set of parameter values) used to assess the intake and dose are inconsistent with the measurement data.

The Guidelines consider the measurement uncertainty as consisting of two categories: Type A and Type B. Type A uncertainties are due to counting statistics which are described in terms of Poisson statistics and Type B uncertainties are due to all other sources of uncertainty such as those relating to calibration(2). Type B uncertainties are described with a single lognormal distribution and SF_B is defined as the geometric standard deviation (GSD).

The measurement M central value and its Type A uncertainty σ_A are given in terms of measured quantities by

$$M = C_n\left(N_G - \frac{N_B}{R_B}\right)$$

$$\sigma_A = C_n\sqrt{N_G + \frac{N_B}{R_B^2}}$$

Where N_G is the number of measured counts, N_B is the number of measured background counts, R_B is the ratio of background count time to sample count time, and C_n is the normalization factor.

The SF for Type A errors is given by:

$$SF_A = \exp\left[\frac{\sigma_A}{M}\right]$$

Typical values for Type A uncertainties have been given by Etherington et al. (2004)(4) for urine and faecal measurements as a function of activity. For example, if the urine activity is 2 mBq then SF_A is about 1.2 and if the faecal activity is 10 mBq then SF_A is about 1.3.

The SF for Type B errors is given by:

$$SF_B = \exp\left[\frac{\sigma_{C_n}}{C_n}\right]$$

where σ_{C_n} is the uncertainty on the normalisation factor.

Based on experienced gained in the IDEAS project, the overall SF can be approximated as follows:

$$\mathrm{SF} = \mathbf{exp}\sqrt{\left[\mathbf{ln}(\mathrm{SF}_{\mathrm{A_i}})\right]^2 + \left[\mathbf{ln}(\mathrm{SF}_{\mathrm{B_i}})\right]^2}$$

This approximation is applicable to cases where the counts are relatively large (i.e. when $SF_A < 1.4$). Miller (2007)$^{(5)}$ considers this lognormal approximation to be reasonable if the ratio $\ln(SF_A) : \ln(SF_B)$ is less than 1/3. In cases where the counts are low (i.e. SF_A is high) then Miller et al. (2002)$^{(6)}$ consider that the exact likelihood function they describe should be used. The exact likelihood function is the probability distribution of measurements given an intake.

The IDEAS Guidelines, therefore, assume the overall uncertainty on an individual monitoring value can be described in terms of a lognormal distribution and the SF is defined as its geometric standard deviation (GSD). Thus, it is assumed that if the measurements could be repeated, hypothetically at the same time, then the distribution of the measurement results could be described by a lognormal distribution.

The default SF values proposed in the IDEAS guidelines are based mainly upon expert judgement. The aim of the present work is to evaluate, mathematically, SF values for different radionuclides and types of monitoring data using real data contained in the IDEAS Internal Contamination Database$^{(3)}$. Results of SF values for some radionuclides and types of monitoring data are presented. Some preliminary results based on this work have already been published$^{(7)}$.

2.2 Procedure

For each case considered it is assumed that the measurements come from the same distribution (i.e. the SF is the same for each measurement).

Data affected by decorporation therapy were excluded. Only those cases with more than 15 data points after the end of exposure were selected. Cases with low levels of activity were avoided so that the main component of the SF would be due to Type B errors. Cases with many <LLD values (i.e. measurements reported as being below the lower limit of detection) were excluded or if a case had <LLD values then the data following the <LLD values were discarded. For each case, the following three steps were carried out.

- *Step 1: Determine the trend of data*

The trend of the data was determined by fitting a sum of exponential terms to the data assuming errors are lognormally distributed (Figure 2.1).

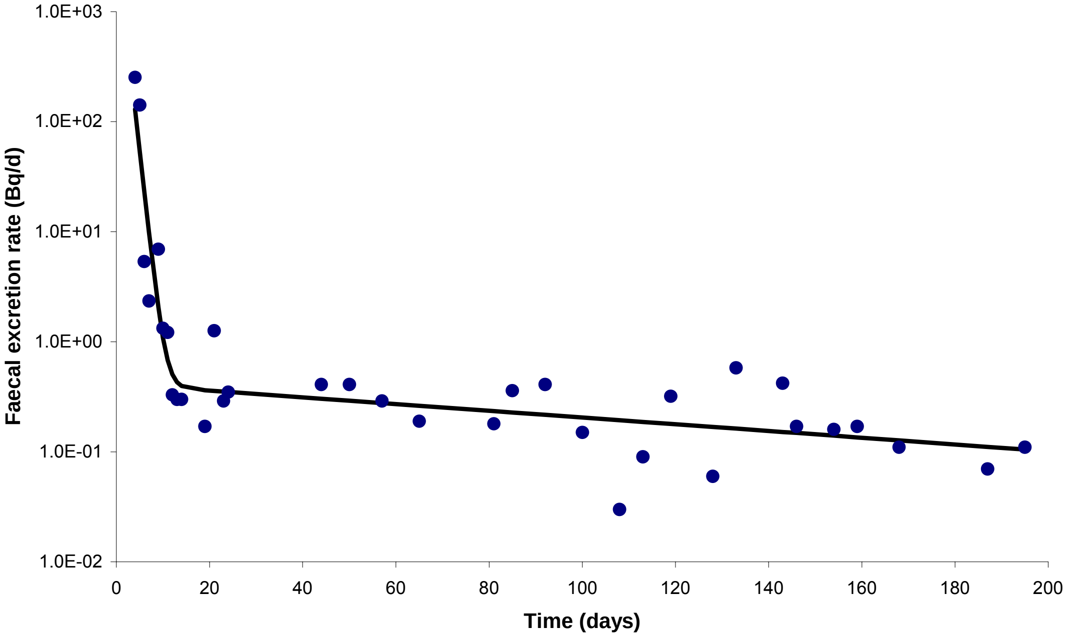


Figure 2.1. A sum of 2 exponential terms fitted to the faecal data of Case 157(3) (inhalation of ^{239}Pu).

The lowest number of exponentials that gives a good fit to the data was used. This was usually determined by the use of the autocorrelation coefficient test statistic (ρ-test statistic)(8). However, in a few cases, the fit was accepted as it was judged that the fit displayed graphically looked reasonable to the eye even though the ρ-test failed.

The ρ-test statistic essentially rejects the fit if all, or a long series of, data are systematically underestimated or overestimated. The advantage of this test statistic is that it is not sensitive to the assumed measurement uncertainty.

- *Step 2: Determine the SF.*

The SF value was determined by calculating the GSD of the data (M_i) around the trend (i.e. predicted quantities, p_i).

$$\sigma^2 = \frac{\sum_{i=1}^{n} \left[ln(M_i) - ln(p_i) \right]^2}{n - z} \quad and \quad SF = e^{\sigma} \qquad (1)$$

Where z is the number of parameters used to determine the trend of the data (two for each exponential term).

- *Step 3: Test to see if the data are lognormally distributed.*

If the measurements are lognormally distributed around the trend of the data then the M_i/p_i values are lognormally distributed with a median of 1.0. The chi-squared (χ^2) test was used to determine whether the distribution of the M_i/p_i values is consistent with a lognormal distribution by comparing the occurrences in the observed frequency distribution with the expected occurrences based on the theoretical lognormal distribution. However, the limitation of the χ^2-test is that it is only valid for large n. So future work will consider other test statistics such as the Anderson-Darling test statistic or the Shapiro-Wilk test statistic.

Figure 2.2 compares the observed normalised cumulative frequency distribution with the theoretical distribution of the M_i/p_i values for the daily faecal excretion data of Case 157(3).

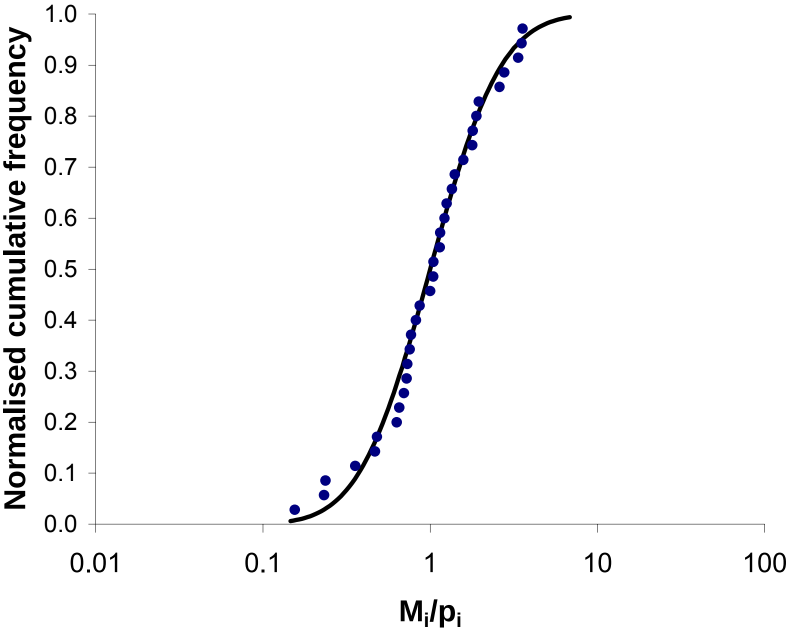


Figure 2.2. Normalised cumulative frequency distribution for the daily faecal excretion data of case 157 [— theoretical; • observed].

2.2.1 Combining data from different cases

Data of the same monitoring type, the same route of intake and the same element from different cases (i.e. subjects) were combined to obtain an overall scattering factor by applying equation (1). For example, if there are two subjects (*a* and *b*) then equation (1) can be extended as follows:

$$\sigma^2 = \frac{\sum_{i=1}^{n^a}\left[ln\left(M_i^a\right) - ln\left(p_i^a\right)\right]^2 + \sum_{i=1}^{n^b}\left[ln\left(M_i^b\right) - ln\left(p_i^b\right)\right]^2}{n^a - z^a + n^b - z^b}$$

where parameters with a superscript *a* refer to subject *a* and parameters with a superscript *b* refer to subject *b*. Again the SF value is equal to exp(σ). Combining data from different cases is valid if the values of M_i/p_i come from the same lognormal distribution.

2.3 Results

In most of the cases it was possible to determine the trend of the data with a single exponential term or with the sum of two exponential terms. A few of the cases required a sum of three exponential terms.

Results for the SF values are presented in Table 2.1. The measurements for the individual cases that had sufficient data (i.e. about n > 35) were found to be consistent with the assumption that the data are lognormally distributed (i.e. the χ^2-test did not fail) apart from one case (Case 42, Pu in urine, wound). When combining the cases, the combined data sets were also consistent with the assumption that the data are lognormally distributed apart from urinary data for plutonium, americium and tritium, and whole body measurements of ^{137}Cs. For these cases it cannot, strictly, be assumed that the values of M_i/p_i come from the same lognormal distribution. Nevertheless, the SF values for the combined cases are given as an indication of the uncertainty in the data.

Table 2.1. Scattering factor (SF) values for different nuclides and types of monitoring data

Nuclide	Type of monitoring	Route of intake[(a)]	No. of cases	No. of data	SF	Range of SF values[(b)]
Pu	Faeces	W	2	111	3.1	2.9 – 3.5
Pu/Am	Faeces	Inh	8	217	2.5	1.9 – 3.5
Pu/Am	Urine	W	8	298	1.8	1.3 –2.4
Pu	Urine	Inh	10	371	1.7	1.4 - 2.0
^{241}Am	Urine	Inh	5	105	1.6	1.2 – 2.2
Uranium	Urine	Inh	4[(c)]	190	1.8	1.4 – 2.0
Uranium	Urine	W (burns)	1	46	1.6	
^{90}Sr	Urine	Inh	4	173	1.6	1.3–1.8
^{60}Co	Urine	Inh	2	20	1.8	1.77-1.82
^{32}P	Urine	Ing or Inj	2	75	1.21	1.15-1.28
^{3}H (HTO)	Urine	Inh	3	233	1.08	1.01-1.10
^{137}Cs	WB count	Inh or Ing	5	103	1.16	1.02-1.27
^{60}Co	WB count	Inh	8	186	1.19	1.07-1.25
^{241}Am	Chest	Inh	1	249[(d)]	1.15	

(a) inh = inhalation, ing = ingestion, inj = injection and W = wound.

(b) Ranges of the SF values calculated for the individual cases.

(c) Other uranium cases were evaluated. For example, there were 3 cases where urine samples were averaged and these cases gave SF values of about of 1.7. Another example included 4 cases where additional intakes could not be ruled out and these gave SF values of about 2.3.

(d) The first 67 measurements were carried out with sodium iodide detectors and subsequent measurements with germanium detectors(9).

2.4 Discussion of results

2.4.1 *Faecal data*

The SF values for faecal excretion range from 1.9 to 3.5 for the individual cases (Table 2.1). These values are at the lower end of the range (2-5) suggested in the IDEAS guidelines. Bull (10) determined SF values between 2 and 3 for systemic faecal excretion from volunteer data, which is in agreement with the values calculated in this document.

The SF values for wound are higher than those from inhalation. Differences may arise because of the different biological processes involved in the uptake and because wound represents systemic faecal excretion whereas for inhalation of relatively insoluble materials a large component is from particle transport from the lung. However, only 2 cases were assessed for wound so no firm conclusions can be drawn. Combining the wound cases with the inhalation cases gives a SF of 2.7. The combined data are consistent with the assumption that the data are lognormally distributed (i.e. the χ^2-test did not fail).

2.4.2 Urine data

In general, for Type B errors, the main component of the SF values results from the uncertainty in the collection period, which depends on the sampling procedures and the technique used to normalise the data to 24-hours. Moss et al. (1969)(11) showed that when the sampling method and analytical procedures are carefully controlled for true 24-h urine samples of plutonium, over 5 days, then the SF is about 1.1 whereas for routine monitoring data the authors obtained a higher value of 1.9. This is in agreement with the SF value calculated from data obtained from a volunteer experiment where the sampling procedures were carefully controlled (Case 127(3), inhalation of fission products). For this case the SF values for urinary excretion of ^{60}Co and ^{137}Cs were less than 1.1. This shows that the scatter caused by biological day-to-day variation is low.

The SF values for urinary excretion of plutonium, americium, uranium, strontium and cobalt are similar, approximately 1.7 (Table 2.1). Also there is little variation between routes of intake. This is expected, as the biological variation is likely to be less than the uncertainty in the collection period. The values ranged from 1.2 to 2.4 for the individual cases.

In general, information on sampling procedures and the method used to normalise the data to 24-hour excretion is not given on the IDEAS database. For one of the Cases (Case 204, Am/Pu, wound) the data were normalised by the amount of creatinine excreted per day. The SF value was about 1.3. At Los Alamos National Laboratory (USA), Type B uncertainties for plutonium in urine measurements normalised using volume or specific gravity were also found to have a SF value of 1.3(12). Plutonium in urine measurements of Sellafield nuclear plant (UK) workers normalised by creatinine indicate a SF value of 1.8(13). However, because sampling procedures and measurement techniques have improved over the years at Sellafield, recent measurements are likely to have a SF value less than 1.8.

For intakes of tritiated water (HTO) the activity concentration in urine is used and not the 24-h excretion rate. As a result the SF is lower (1.1).

2.4.3 In-vivo data

The SF values for whole body measurements of ^{137}Cs and ^{60}Co, which emit high-energy photon radiation, are on average 1.16 and 1.19 respectively. These values are similar, with the IDEAS suggested value of 1.2 for in-vivo measurements of radionuclides emitting high-energy photon radiation.

2.5 Suggested SF values for various types of measurement

The SF values for different types of measurement given in Table 2.2 are suggested as default values where information specific to the case is not available. These values are based upon the work carried out here, the values suggested by the IDEAS project(2) and upon the studies of Moss et al. (1969)(11), Riddell and Britcher (1994)(13) and Miller (2004)(12).

Table 2.2 Default values for the scattering factor (SF) for various types of measurement from different studies (Type B errors). Ranges are given in parentheses

Quantity	Type B scattering factor, SF_B
True 24-hr urine	1.1(a)
Activity concentration of ^{3}H in urine	1.1(b)
Simulated 24-hr urine, creatinine or specific gravity normalised.	1.7(b) (1.3(c) - 1.8(d))
Spot urine sample	2.0(a)
Faecal 24-hr sample	3 (2 - 4)(b)
Faecal 72-hr sample	1.9 (1.5 – 2.2)(e)
Chest count (see Table 2.3)	1.2 to 2.1

(a) Value given by Moss et al, 1969(11) based on plutonium in urine measurements of workers at Los Alamos.

(b) Value based on values calculated here, Marsh et al. (2007)(7).

(c) At Los Alamos, Type B uncertainties, in terms of the coefficient of variation, for urine samples normalised using volume and specific gravity has been found to be 30% (i.e. a SF of 1.3)(12).

(d) Value given by Riddell et al, 1994(13) based on plutonium in urine measurements of Sellafield workers. Because sampling procedures and measurements techniques have improve over the years recent measurements are likely to have a SF less than 1.8.

(e) SF values for 72-hr faecal samples are consistent with 24-hr faecal samples.

The SF values for chest and total body in-vivo measurements are given in Table 2.3. These are the same values as suggested by the IDEAS project(2). These values are also consistent with the values determined here. It is noted that specialised in-vivo measurements such as knee and head measurements to determine skeleton activity have much larger uncertainties compared with chest and total body activity measurements. For example, Vrba (2007)(14) calculated differences in the calibration factor of about 20% due to variation in activity distribution for head measurements of ^{241}Am whereas for chest measurements the corresponding uncertainty is only about 5%(2).

Table 2.3 Typical values for the Type A and Type B scattering factors (SF) for *in vivo* chest and total body measurements of radionuclides emitting low, intermediate and high photon energy radiation

Uncertainty type	Log. normal scattering factor SF		
	Low photon energy E < 20 keV	Intermediate photon energy 20 keV < E < 100 keV	High photon energy E > 100 keV
Type A	1.5	1.3	1.07
Type B	2.06	1.25	1.15
Total	2.3	1.4	1.2

2.6 Conclusions on SF values

In this study an empirical approach based on statistical analysis of real monitoring data taken from the IDEAS Internal Contamination Database has been used to evaluate SF values. Results have been presented in Table 2.1 for different types of monitoring data. Results are broadly in agreement with the values suggested in the IDEAS Guidelines, which were based mainly on expert judgement. However, the SF values for faecal excretion (1.9 to 3.5) are at the lower end of the range (2 to 5) suggested in the IDEAS Guidelines.

Based upon the results of this work and on other studies(2,11,12,13) the CONRAD group suggests the SF values for different types of monitoring data given in Tables 2.2 and 2.3 as default values where information specific to the case is not available.

3 UNCERTAINTY STUDIES

In this section an application of statistical methods to retrospective dose assessment are considered by the example of an inhalation of tritiated water (HTO) case, where a single routine monitoring measurement has been made and the time of intake within the monitoring period is unknown. Two main approaches to statistical inference have been considered: the frequentist (classical) approach and the Bayesian approach.

In the frequentist method, probability is interpreted as a limiting frequency of the outcome of a repeatable experiment (e.g. measurement of a tritium activity in a urine sample). The uncertainty of a given parameter value is expressed in terms of a confidence interval with a specified level of confidence, for example the 95% confidence interval. It is important to realise that the parameter value is unknown but has a fixed true value whereas the ends of the confidence interval are random. This means that, for example, the 95% confidence interval is interpreted as follows: If the experiment is repeated many times, calculating a confidence interval each time, then 95% of the intervals would include the true fixed parameter value. In the frequentist method one cannot therefore define a probability for a hypothesis or a probability density function (pdf) for a parameter. However, the pdf for a parameter *estimate* can be inferred from the frequency distribution of the outcome (e.g. the pdf for the intake estimate can be inferred from the frequency distribution of the measurements).

In the Bayesian method, the interpretation of probability is more general and includes *degree of belief*. One can then speak of a probability density function for a parameter, which expresses one's state of knowledge about where its true value lies. Using Bayes' theorem the prior degree of belief (i.e. what is known about a parameter value before the measurements are observed) is updated by the data giving a posterior pdf for the parameter.

Sections 3.1 and 3.2 give an overview of frequentist and Bayesian approaches. For illustrative purposes both approaches are applied to the HTO example in Sections 3.4 and 3.5.

3.1 Frequentist approach

The frequentist approach is based on evaluating the pdf of observing the measurement data given the model parameter values. This pdf is sometimes referred to as the sampling distribution or the likelihood function.

As stated above the uncertainty of a parameter being estimated is expressed by a confidence interval. To calculate the confidence interval, the sampling distribution, $f(M|I)$ is required where M represents the outcome of an experiment, e.g. the result of the measurement of a tritium activity in a urine sample, and I is the unknown parameter, e.g. intake. The corresponding cumulative distribution, $F(M_{exp}|,I)$ can be derived as follows:

$$F(M_{\exp}|I) = \int_0^{M_{\exp}} f(M|I)dM$$

Where $F(M_{exp,}|I)$ is the probability that $M < M_{exp}$ for a given value of I.

For a pre-specified probability α and a given measurement result of M_{exp}, there are two values of I such that

$$F(M_{\exp}|I_{\alpha/2}) = 1-\alpha/2 \text{ and } F(M_{\exp}|I_{1-\alpha/2}) = \alpha/2 \qquad (1)$$

Where $I_{\alpha/2}$ and $I_{1-\alpha/2}$ are the lower and upper endpoints of the confidence interval with a level of confidence of 1- α.

The best estimate of a parameter can be defined as the median value (i.e. the value with α=0.5, e.g $I_{0.5}$). This has the advantage of dividing the confidence interval into two parts having equal coverage probability.

The sampling distribution $f(M|I)$ can be also used to infer pdf for the *intake estimate* that can be compared with the true value of intake I. The intake estimate, I_{est}, is defined as

$$I_{est} = \frac{M}{C_{est}}$$

where C_{est} is a constant dependent on the assumptions used to estimate the intake.

The pdf for the intake estimate is calculated as

$$f_{est}(I_{est}|I) = \frac{f(M|I)}{C_{est}}$$

Calculations have been performed to calculate $f_{est}(I_{est}|I)$ to investigate different approaches used for estimating the intake from routine monitoring (Section 3.6).

3.2 Bayesian approach

Puncher and Birchall (2007)$^{(15)}$ and Miller et al. (2003)$^{(16)}$ have applied Bayesian techniques to determine uncertainties on dose assessments. The joint posterior distribution of intake and the model parameters, given the data, $P(I,L|\mathbf{M})$, can be determined using Bayes' theorem:

$$P(I,\mathbf{L}\,|\,\mathbf{M}).dI.d\mathbf{L} = C.P(\,\mathbf{M}\,|\,I,\mathbf{L}).\,p(I).\,p(\,\mathbf{L}\,).dI.d\mathbf{L}$$

Where

L	A vector of *n* model parameters.
M	A vector containing measurement data.
I	The unknown intake.
*P(M|I,**L**)*	The probability density function (pdf) of observing the measurement data given the intake and model parameters and is called the likelihood function.
*p(**L**)*	The prior pdf of the model parameters. This represents what is known about the parameters before the measurement data is observed.
p(I)	The prior pdf of intake. This represents what is known about the intake before the measurement data is observed.
C	A constant of normalisation. 1/*C* is the probability of observing dataset *M*.

Bayesian methods update what is known about model parameters and the unknown intake (the prior probability) with new information in the form of measurement data, to generate a posterior distribution. The latter represents the new knowledge about the parameters and intake given the observed data. In general, as the number of measurements increase the data become more informative and can reduce the uncertainty on the parameter values that are specified by the prior. In other words, the posterior distribution is mainly influenced by the likelihood function when there are comprehensive data.

The best estimate of intake is defined, here, as the mean value (i.e. expectation value) of the posterior distribution of the intake given the measurement data.

3.3 Tritiated water (HTO) example

For simplicity, only a single monitoring period was considered. The following assumptions were assumed:

- A monitoring period, *T* of 30 d.
- A measurement value, *M* of 6.40E-3 Bq/l in the urine at the end of a monitoring period.
- A measurement error of 10%, with a normal distribution. (i.e. σ_M = 6.4E-4 Bq/l)
- The prior distributions on the intake and on the time of intake are both uniform.
- The ICRP Publication 56 biokinetic model for tritium.
- Route of intake was inhalation

3.4 Application of Bayesian approach to the HTO example.

The posterior distributions of the intake, *P(I| M)* and the time of intake, *P(t| M)* given the measurement can be derived as follows:

$$P(I\,|\,M) = C \cdot \int_{-\infty}^{\infty} \cdot P(M\,|\,I,t) \cdot p(t) \cdot p(I) \cdot \mathrm{d}t$$

$$P(t\,|\,M) = C \cdot \int_{-\infty}^{\infty} P(M\,|\,I,t) \cdot p(t) \cdot p(I) \cdot \mathrm{d}I$$

Where C is a constant; *P(M|t,I)* is the pdf of observing measurement *M* given *t* and *I* ; *p(I)* and *p(t)* are prior pdfs of the intake and the intake time.

In this example, it is assumed that the measurements are normally distributed with a 10% relative error (i.e. σ_M = 6.4E-4 Bq/l), so the likelihood function is given by:

$$P(M\mid I,t) = \frac{1}{\sqrt{2\pi}\cdot\sigma_M}\cdot\exp\left\{-\frac{[M - I\cdot m(T-t)]^2}{2\cdot{\sigma_M}^2}\right\}$$

Where *m(T-t)* is the predicted activity concentration of ^{3}H in urine (Bq/l) following unit intake at time *t*. The following equation was used for *m(t)* and is consistent with the ICRP Publication 56 model for HTO.

$$m(t) = (1/42)\cdot\left(0.97\cdot e^{-\ln(2)\cdot t/10} + 0.03\cdot e^{-\ln(2)\cdot t/40}\right) \qquad (1)$$

The posterior distributions of the intake, *P(I| M)* and the time of intake, *P(t| M)* are given in Figures 3.1 and 3.2 respectively.

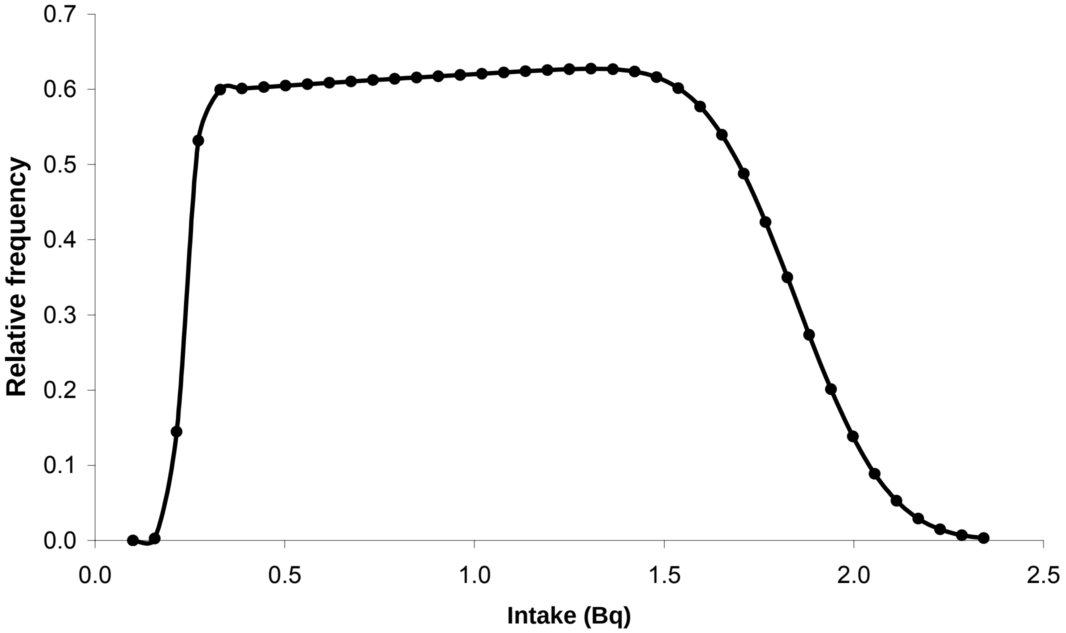


Figure 3.1 Posterior distribution of the intake, *P(I| M)* for the HTO example. (*T*=30 d, *M* = 6.40E-3 Bq/l, σ_M = 6.4E-4 Bq/l.)

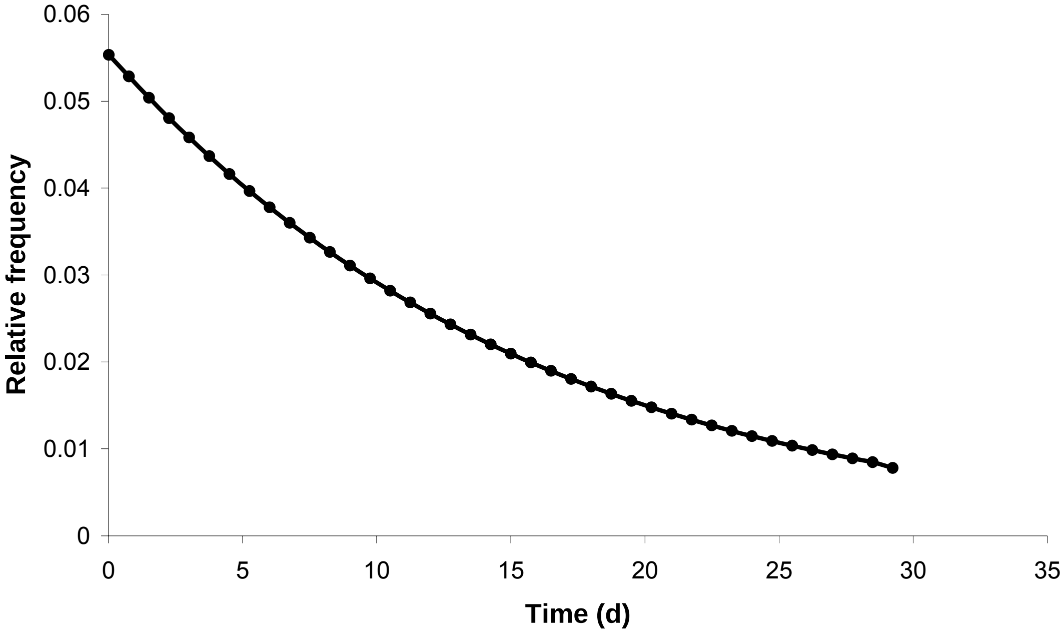


Figure 3.2 Posterior distribution of the time of intake, *P(t| M)* for the HTO example. (*T*=30 d, *M* = 6.40E-3 Bq/l, σ_M = 6.4E-4 Bq/l.)

Note that, in this case, the posterior distribution of the time of intake, *P(t| M)* is not uniform (i.e. not the same as the prior distribution, *p(t)*) because due to Bayes' formula, the prior degree of belief is updated by the single data point from the experiment. This result is at first sight counter intuitive, especially when nothing is known about *I* and *p(t)*, and has been overlooked in some analyses(17). However, it is acknowledged that for a single measurement, *P(t| M)* is strongly dependent upon the assumed prior distributions of *p(t)* and *p(I)*.

A credible confidence interval for *I* can be obtained from the posterior distribution *P(I| M)*. In this example, the 90% credible interval is (0.3 Bq, 1.8 Bq). The interpretation of the 90% credible interval is that, there is a 90% probability that the true intake is within the interval.

3.5 Application of frequentist approach to the HTO example.

In the frequentist approach a sampling distribution *f(M|I)* is used to infer a confidence interval representing the uncertainty of a parameter being estimated. For the HTO example, a sampling distribution can be calculated by Monte Carlo integration technique using equation:

$$M = I \cdot m(T - t) + \Delta M$$

where

ΔM	is a statistical error of measurement and in this example, it is assumed to be normally distributed with a mean of zero and a σ_M = 6.4E-4 Bq/l.
m(T-t)	is given by equation (1) for this example.

Monte Carlo integration technique consists of obtaining possible values of the output quantity *M* by combining possible values of input quantities (ΔM and *t*) and then sorting them to produce a frequency distribution *f(M|I)*. In this example, *t* is selected from a uniform distribution to give *f(M|I)*.

In Figure 3.3, a set of a cumulative sampling distributions *F(M|I)* is shown for a set of intake values.

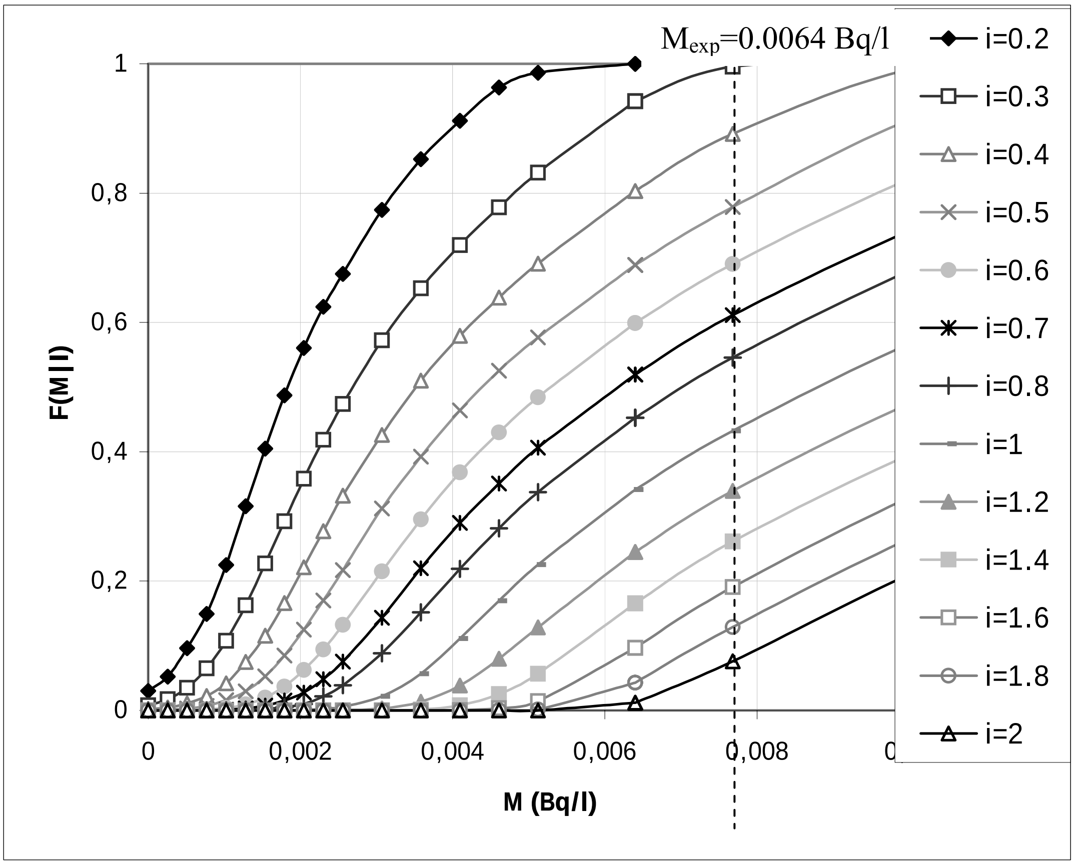


Figure 3.3 Cumulative sampling distributions, *F(M|I)* for a set of intake values, assuming a uniform distribution of time of intake. (HTO example with *T*=30 d, M_{exp} = 6.40E-3 Bq/l and σ_M = 6.4E-4 Bq/l.)

For a pre-specified probability α and a given measurement result of M_{exp}, the endpoints of the confidence interval can be determined from equation (1), which is repeated here:

$$F(M_{\exp}|I_{\alpha/2}) = 1 - \alpha/2 \text{ and } F(M_{\exp}|I_{1-\alpha/2}) = \alpha/2$$

Where $I_{\alpha/2}$ and $I_{1-\alpha/2}$ are the lower and upper endpoints of the confidence interval with a level of confidence of 1- α.

In this example, M_{exp} = 6.40E-3 Bq/l, and the 90% confidence interval is (0.3 Bq, 1.8 Bq).

3.6 Intake pattern assumptions

To estimate intakes from routine monitoring data ICRP recommends an assumption that the intake occurs at the mid-point of the monitoring period. Puncher et al. (2006)$^{(17)}$ and Birchall et al. (2007)$^{(18\ )}$ showed that this mid-point method leads to biased estimates of intake. That is if this method is applied over a long period of time it will tend to, on average, overestimate the worker's real intake. In order to avoid this biasing the authors suggested that a constant chronic intake throughout the monitoring interval should be assumed. This was shown to lead to unbiased estimates of intake, i.e. if this constant chronic method is applied over a long period of time, on average it will tend to estimate the worker's total true intake. Work carried out within this project has also shown this to be true when the measurement uncertainty is assumed to have a normal distribution, (i.e. the measurement itself is unbiased). It was also shown by example of the HTO case, that more than 50% of the workers will have their intake underestimated compared with the true value if the constant chronic method is applied. This is illustrated in Figure 3.4, which shows cumulative distributions for the intake estimate, I_{cc} obtained with the constant chronic method. Two extreme intake time patterns were considered: (1) a true single intake of 100 Bq at a random time and (2) a true constant chronic of 100 Bq. It was also shown for the mid-point method that more than 50% of the workers have their intake overestimated.

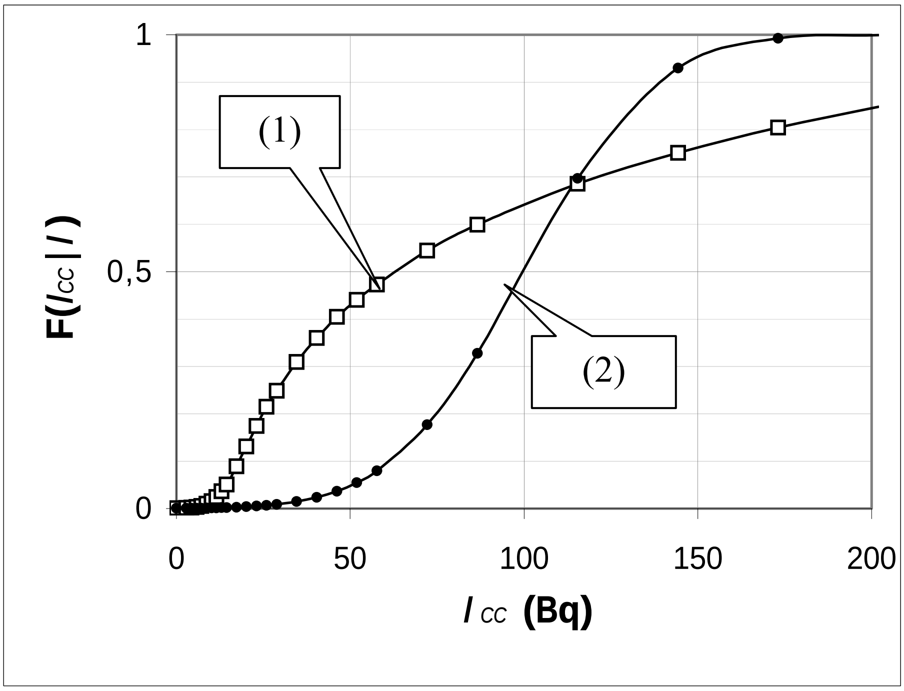


Figure 3.4 Cumulative distributions, *F(I_{cc} | I)*, for the constant chronic intake estimate, I_{cc} for two intake time patterns: single intake at random time (1) and constant chronic intake (2). (HTO example with *T* = 50 d, *I* = 100 Bq, $\sigma_{M_{\exp}}$ = 0.3 Bq).

3.7 Future work

Special monitoring is generally carried out following inadvertent exposures and the time of intake is known. The IDEAS guidelines suggest the number and type of data required for the assessment of dose. The greater the initial dose assessment the more data is required in order to reduce the uncertainty on the dose assessment. The number and type of data required was based on judgement and is open for discussion. One way to obtain a quantitative approach in deciding the number of data required, is to carry out uncertainty studies. The Bayesian approach can be used to estimate the conditional probability of the intake or dose given the measurement data for special monitoring programmes. Such studies can be used to determine the minimum number of measurements required to estimate an intake and dose with a given uncertainty.

Uncertainty studies can also be used to optimise the design of routine monitoring programmes so that the uncertainty in the assessed dose is minimised(19). In this study a simple example of HTO inhalation intake was studied where only the measurement errors and the uncertainty in the time of intake were considered. Future uncertainty studies should consider routine monitoring programmes for other radionuclides and additional model parameters should be considered such as absorption type and aerosol particle size (AMAD). Different types of measurement errors (Type A and B) should also be consider as well as several monitoring intervals.

3.8 Conclusions on uncertainty studies

The frequentist (classical) and Bayesian methods represent two main approaches to statistical inference in retrospective dose assessment.

The frequentist method provides the usual tools for reporting the outcome of the experiment *given a model* without the need to incorporate prior beliefs concerning the parameter being estimated. The uncertainty of a given parameter value is expressed in terms of a confidence interval. The endpoints of the confidence interval are random variables whereas the unknown parameter is a constant with a fixed true value.

The Bayesian approach provides the tools to derive the posterior pdf for a given parameter. The measurement data updates the prior degree of belief (i.e. what is known about a parameter value before the measurements are observed) to give a posterior pdf for the parameter. It is shown by example of the HTO case, where a uniform prior was assumed for both the intake, $p(I)$ and the time of intake, $p(t)$, that even a single measurement can update $p(t)$ to give a non-uniform posterior distribution, $p(t|M)$. However, it must be emphasised that for a single measurement, $P(t|M)$ is strongly dependent upon the assumed prior distributions of $p(t)$ and $p(I)$. As the number of measurements increase, the posterior pdf can be less dependent upon the prior distributions, in which case it is more justifiable to infer conclusions from the posterior distribution.

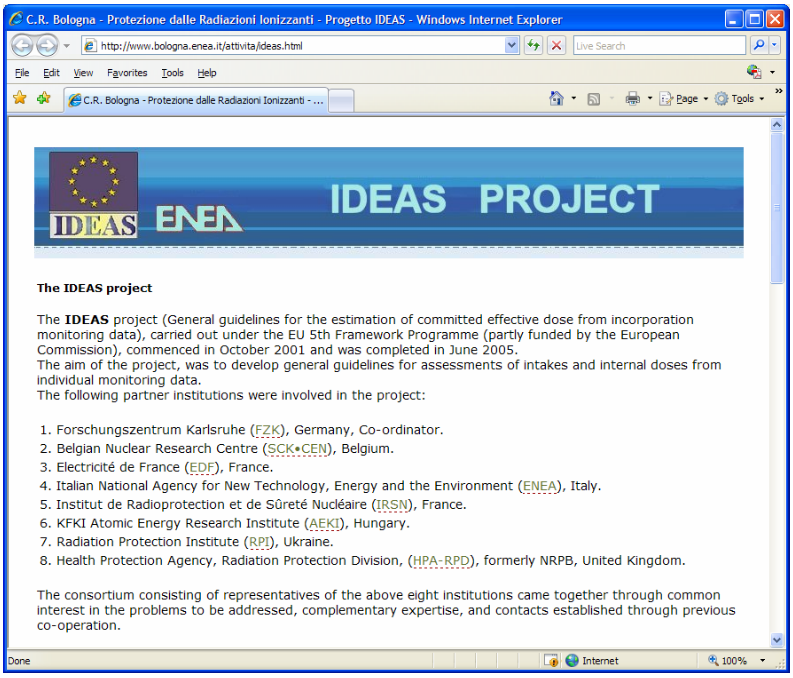
The sampling distribution can be also used to infer a pdf for the *intake estimate* that can be compared with the true value of intake I. In this way it is shown by example of the HTO case that more than 50% of the workers will have their intake underestimated compared with the true value if the constant chronic method is applied. For the mid-point method more than 50% of the workers have their intake overestimated. On the other hand for routine monitoring, assuming a constant chronic throughout the monitoring interval yields unbiased estimates of intake if the measurement itself is unbiased.

4 ENEA/ IDEAS WEB PAGE

4.1 Introduction

One of the aims of the Work Package 5.1 for the refinements of the IDEAS Guidelines has been to realize a new web page to be used inside the CONRAD project, to make available all the documents elaborated during the project.

In mid 2006, the page http://www.bologna.enea.it/attivita/ideas.html has been established inside the ENEA Bologna web site. The structure of the web page is as follows.


C.R. Bologna - Protezione dalle Radiazioni Ionizzanti - Progetto IDEAS - Windows Internet Explorer
http://www.bologna.enea.it/attivita/ideas.html
Live Search
File Edit View Favorites Tools Help
C.R. Bologna - Protezione dalle Radiazioni Ionizzanti - ...
Page Tools
IDEAS
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IDEAS PROJECT
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Internet
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The IDEAS project

The **IDEAS** project (General guidelines for the estimation of committed effective dose from incorporation monitoring data), carried out under the EU 5th Framework Programme (partly funded by the European Commission), commenced in October 2001 and was completed in June 2005.
The aim of the project, was to develop general guidelines for assessments of intakes and internal doses from individual monitoring data.
The following partner institutions were involved in the project:

1. Forschungszentrum Karlsruhe (FZK), Germany, Co-ordinator.
2. Belgian Nuclear Research Centre (SCK•CEN), Belgium.
3. Electricité de France (EDF), France.
4. Italian National Agency for New Technology, Energy and the Environment (ENEA), Italy.
5. Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France.
6. KFKI Atomic Energy Research Institute (AEKI), Hungary.
7. Radiation Protection Institute (RPI), Ukraine.
8. Health Protection Agency, Radiation Protection Division, (HPA-RPD), formerly NRPB, United Kingdom.

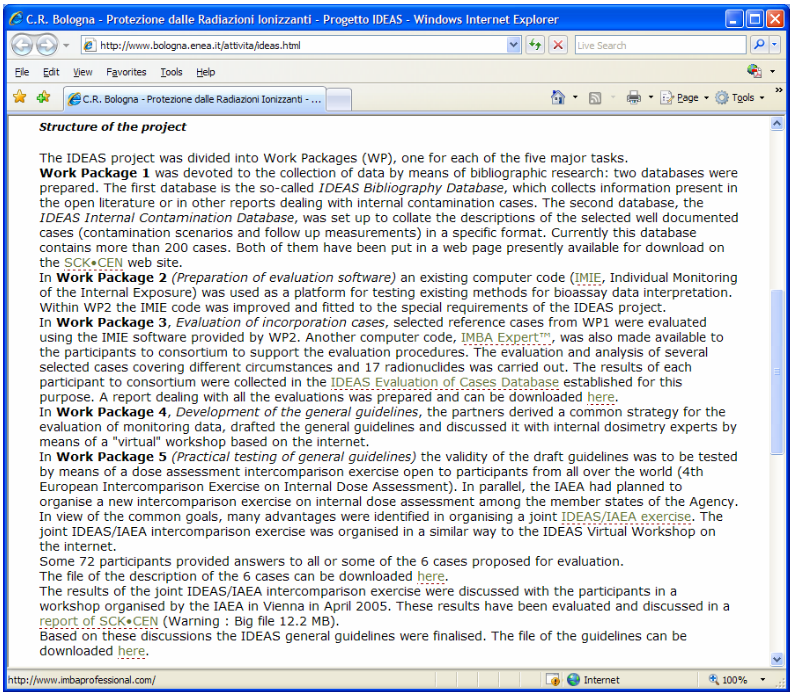
The consortium consisting of representatives of the above eight institutions came together through common interest in the problems to be addressed, complementary expertise, and contacts established through previous co-operation.

Figure 4.1: Display of the first part of the ENEA / IDEAS web page

The first part of the web page is devoted to the presentation of the institutions participating to the Project IDEAS with the link to the main page of each institution. In Figure 4.1 the structure of the first part of the web page is reported.

4.2 Structure of the IDEAS Project

The following part (second part) is related to the description of the structure of the IDEAS project and of the main activities that have been performed during its development (see Figure 4.2). For each Work Package (WP) a brief description with the main link to download representative documents is provided. Regarding WP1 in which the Bibliography and the Internal Contamination Databases had been set up a link to the SCK.CEN IDEAS web page is provided to access the different databases and for the download of them. In the same page is also available the download of the Evaluation of Cases Database developed during WP3 (see Figure 4.3).


C.R. Bologna - Protezione dalle Radiazioni Ionizzanti - Progetto IDEAS - Windows Internet Explorer
http://www.bologna.enea.it/attivita/ideas.html
Live Search
File Edit View Favorites Tools Help
C.R. Bologna - Protezione dalle Radiazioni Ionizzanti - ...
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Tools
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Internet
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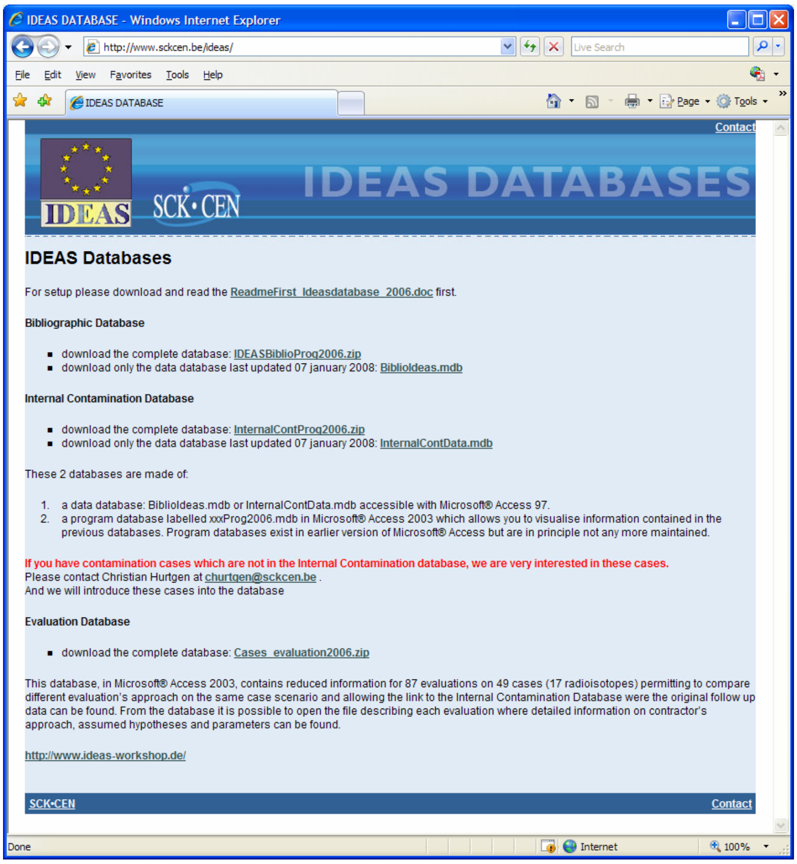
Structure of the project

The IDEAS project was divided into Work Packages (WP), one for each of the five major tasks. **Work Package 1** was devoted to the collection of data by means of bibliographic research: two databases were prepared. The first database is the so-called *IDEAS Bibliography Database*, which collects information present in the open literature or in other reports dealing with internal contamination cases. The second database, the *IDEAS Internal Contamination Database*, was set up to collate the descriptions of the selected well documented cases (contamination scenarios and follow up measurements) in a specific format. Currently this database contains more than 200 cases. Both of them have been put in a web page presently available for download on the SCK•CEN web site.
In **Work Package 2** *(Preparation of evaluation software)* an existing computer code (IMIE, Individual Monitoring of the Internal Exposure) was used as a platform for testing existing methods for bioassay data interpretation. Within WP2 the IMIE code was improved and fitted to the special requirements of the IDEAS project.
In **Work Package 3**, *Evaluation of incorporation cases*, selected reference cases from WP1 were evaluated using the IMIE software provided by WP2. Another computer code, IMBA Expert™, was also made available to the participants to consortium to support the evaluation procedures. The evaluation and analysis of several selected cases covering different circumstances and 17 radionuclides was carried out. The results of each participant to consortium were collected in the IDEAS Evaluation of Cases Database established for this purpose. A report dealing with all the evaluations was prepared and can be downloaded here.
In **Work Package 4**, *Development of the general guidelines*, the partners derived a common strategy for the evaluation of monitoring data, drafted the general guidelines and discussed it with internal dosimetry experts by means of a "virtual" workshop based on the internet.
In **Work Package 5** *(Practical testing of general guidelines)* the validity of the draft guidelines was to be tested by means of a dose assessment intercomparison exercise open to participants from all over the world (4th European Intercomparison Exercise on Internal Dose Assessment). In parallel, the IAEA had planned to organise a new intercomparison exercise on internal dose assessment among the member states of the Agency. In view of the common goals, many advantages were identified in organising a joint IDEAS/IAEA exercise. The joint IDEAS/IAEA intercomparison exercise was organised in a similar way to the IDEAS Virtual Workshop on the internet.
Some 72 participants provided answers to all or some of the 6 cases proposed for evaluation.
The file of the description of the 6 cases can be downloaded here.
The results of the joint IDEAS/IAEA intercomparison exercise were discussed with the participants in a workshop organised by the IAEA in Vienna in April 2005. These results have been evaluated and discussed in a report of SCK•CEN (Warning : Big file 12.2 MB).
Based on these discussions the IDEAS general guidelines were finalised. The file of the guidelines can be downloaded here.

Figure 4.2: Part 2: description of the activities performed in the various IDEAS work packages


IDEAS DATABASE - Windows Internet Explorer
http://www.sckcen.be/ideas/
Live Search
File Edit View Favorites Tools Help
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IDEAS Databases

For setup please download and read the ReadmeFirst_Ideasdatabase_2006.doc first.

Bibliographic Database

- download the complete database: IDEASBiblioProg2006.zip
- download only the data database last updated 07 january 2008: BiblioIdeas.mdb

Internal Contamination Database

- download the complete database: InternalContProg2006.zip
- download only the data database last updated 07 january 2008: InternalContData.mdb

These 2 databases are made of:

1. a data database: BiblioIdeas.mdb or InternalContData.mdb accessible with Microsoft® Access 97.
2. a program database labelled xxxProg2006.mdb in Microsoft® Access 2003 which allows you to visualise information contained in the previous databases. Program databases exist in earlier version of Microsoft® Access but are in principle not any more maintained.

If you have contamination cases which are not in the Internal Contamination database, we are very interested in these cases.
Please contact Christian Hurtgen at churtgen@sckcen.be .
And we will introduce these cases into the database

Evaluation Database

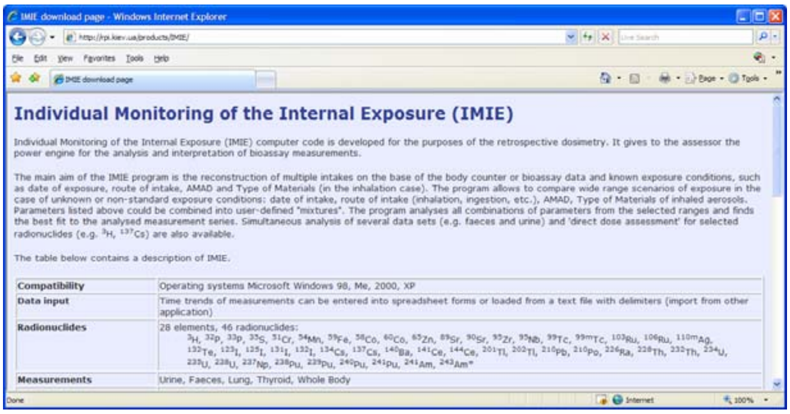
- download the complete database: Cases_evaluation2006.zip

This database, in Microsoft® Access 2003, contains reduced information for 87 evaluations on 49 cases (17 radioisotopes) permitting to compare different evaluation's approach on the same case scenario and allowing the link to the Internal Contamination Database were the original follow up data can be found. From the database it is possible to open the file describing each evaluation where detailed information on contractor's approach, assumed hypotheses and parameters can be found.

http://www.ideas-workshop.de/

Figure 4.3: Layout of the SCK.CEN IDEAS databases page.

In relationship to the activities performed during WP2 (Preparation of evaluation software) a link to the web page of the Ucranian Radiation Protection Institute which developed the IMIE software which has been used during the evaluations of WP3, is provided (see Figure 4.3).


IMIE download page - Windows Internet Explorer
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Individual Monitoring of the Internal Exposure (IMIE)

Individual Monitoring of the Internal Exposure (IMIE) computer code is developed for the purposes of the retrospective dosimetry. It gives to the assessor the power engine for the analysis and interpretation of bioassay measurements.

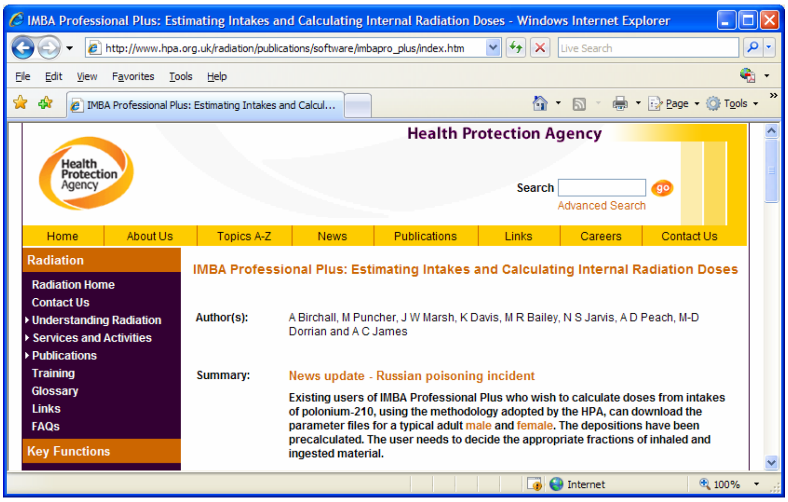
The main aim of the IMIE program is the reconstruction of multiple intakes on the base of the body counter or bioassay data and known exposure conditions, such as date of exposure, route of intake, AMAD and Type of Materials (in the inhalation case). The program allows to compare wide range scenarios of exposure in the case of unknown or non-standard exposure conditions: date of intake, route of intake (inhalation, ingestion, etc.), AMAD, Type of Materials of inhaled aerosols. Parameters listed above could be combined into user-defined "mixtures". The program analyses all combinations of parameters from the selected ranges and finds the best fit to the analysed measurement series. Simultaneous analysis of several data sets (e.g. faeces and urine) and 'direct dose assessment' for selected radionuclides (e.g. ^{3}H, ^{137}Cs) are also available.

The table below contains a description of IMIE.

Compatibility	Operating systems Microsoft Windows 98, Me, 2000, XP
Data input	Time trends of measurements can be entered into spreadsheet forms or loaded from a text file with delimiters (import from other application)
Radionuclides	28 elements, 46 radionuclides: ^{3}H, ^{32}P, ^{33}P, ^{35}S, ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{65}Zn, ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{99}Tc, ^{99m}Tc, ^{103}Ru, ^{106}Ru, ^{110m}Ag, ^{132}Te, ^{123}I, ^{125}I, ^{131}I, ^{132}I, ^{134}Cs, ^{137}Cs, ^{140}Ba, ^{141}Ce, ^{144}Ce, ^{201}Tl, ^{202}Tl, ^{210}Pb, ^{210}Po, ^{226}Ra, ^{228}Th, ^{232}Th, ^{234}U, ^{235}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, ^{243}Am*
Measurements	Urine, Faeces, Lung, Thyroid, Whole Body

Figure 4.4: Web page of the IMIE software inside the Ucranian Radiation Protection Institute web site

In WP3 (Evaluation of incorporation cases) another computer code IMBA Professional™ had been made available to the consortium for the evaluation of cases. A link to the IMBA HPA web page is present (see Figure4.5).



IMBA Professional Plus: Estimating Intakes and Calculating Internal Radiation Doses

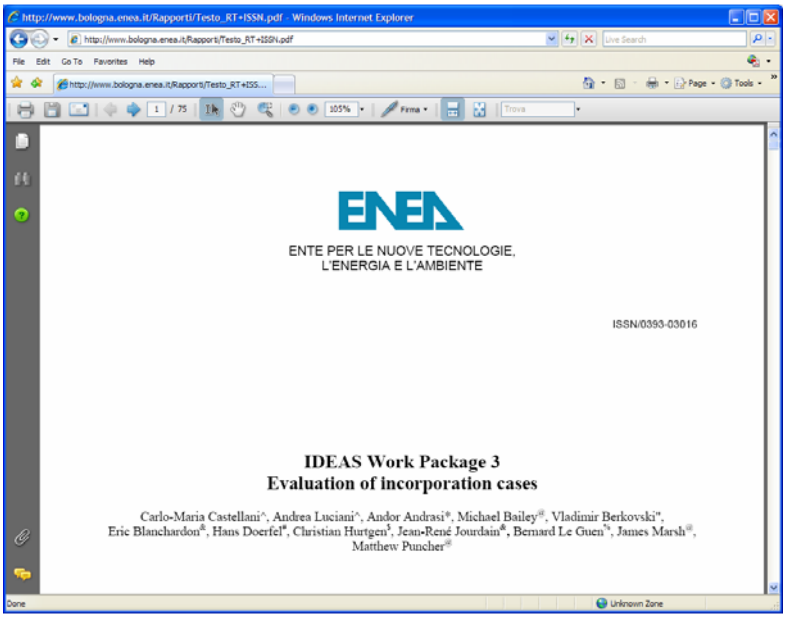
Author(s): A Birchall, M Puncher, J W Marsh, K Davis, M R Bailey, N S Jarvis, A D Peach, M-D Dorrian and A C James

Summary: News update - Russian poisoning incident

Existing users of IMBA Professional Plus who wish to calculate doses from intakes of polonium-210, using the methodology adopted by the HPA, can download the parameter files for a typical adult male and female. The depositions have been precalculated. The user needs to decide the appropriate fractions of inhaled and ingested material.

Figure 4.5: Web page of the IMBA Professional™ software inside the British Health Protection Agency web site.

For the WP3 the final report of the work package is available for downloading (see Figure 4.6).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ENEA
ENTE PER LE NUOVE TECNOLOGIE,
L'ENERGIA E L'AMBIENTE

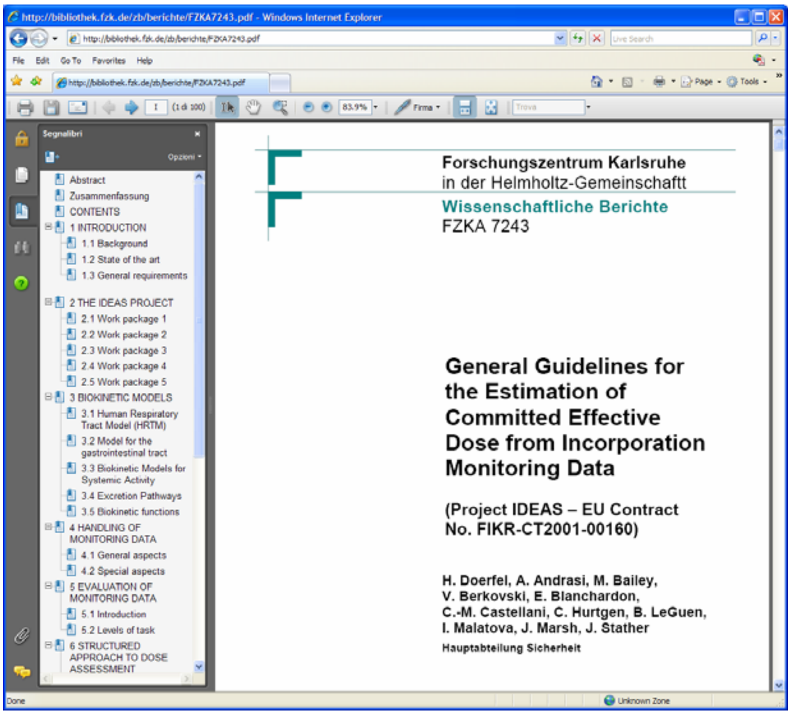
ISSN/0393-03016

IDEAS Work Package 3
Evaluation of incorporation cases

Carlo-Maria Castellani[^], Andrea Luciani[^], Andor Andrasi[*], Michael Bailey[@], Vladimir Berkovski["],
Eric Blanchardon[&], Hans Doerfel[#], Christian Hurtgen[$], Jean-René Jourdain[&], Bernard Le Guen[%], James Marsh[@],
Matthew Puncher[@]

Figure 4.6: Final report of IDEAS Work Package 3 Evaluation of Incorporation Cases.

Regarding Work Package 4, which is related to the development of the general guidelines, the full text of the guidelines, is available (see Figure 4.7).



Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaftt
Wissenschaftliche Berichte
FZKA 7243

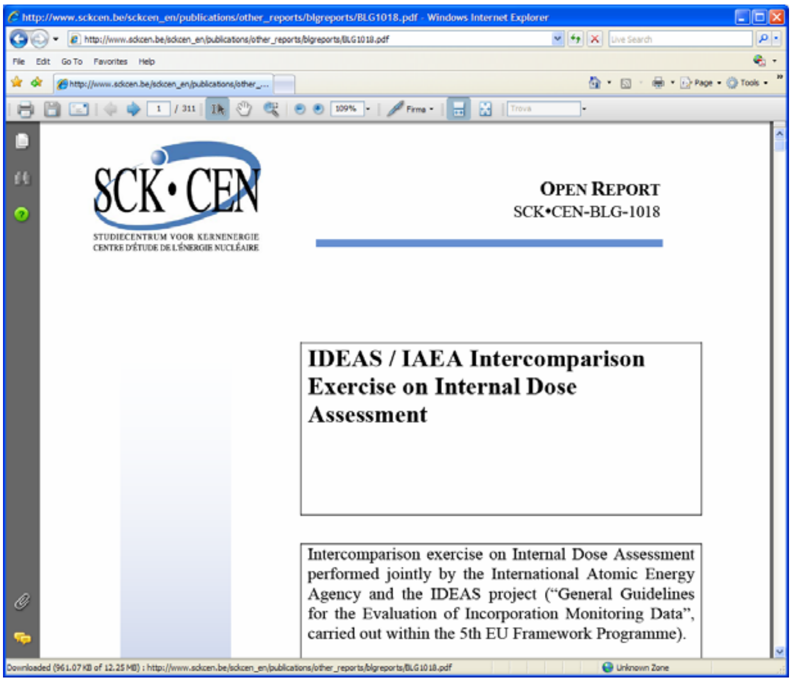
General Guidelines for the Estimation of Committed Effective Dose from Incorporation Monitoring Data

(Project IDEAS – EU Contract No. FIKR-CT2001-00160)

H. Doerfel, A. Andrasi, M. Bailey,
V. Berkovski, E. Blanchardon,
C.-M. Castellani, C. Hurtgen, B. LeGuen,
I. Malatova, J. Marsh, J. Stather
Hauptabteilung Sicherheit

Figure 4.7: Report on General Guidelines IDEAS

For the WP5 (Practical testing of the IDEAS Guidelines) the IDEAS/ IAEA intecomparison exercise is presented. The file of the description of the 6 case studies can be downloaded as well as the final SCK.CEN BLG – 1018 report with the full description of the evaluation of the intercomparison exercise and the general conclusions presented during the workshop held in April 2005 in the IAEA Headquarters in Vienna (see Figure 4.8).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http://www.sckcen.be/sckcen_en/publications/other_reports/blgreports/BLG1018.pdf
Live Search
File
Edit
Go To
Favorites
Help
http://www.sckcen.be/sckcen_en/publications/other_...
Page
Tools
1
/ 311
109%
Firma
Trova
SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
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OPEN REPORT
SCK•CEN-BLG-1018

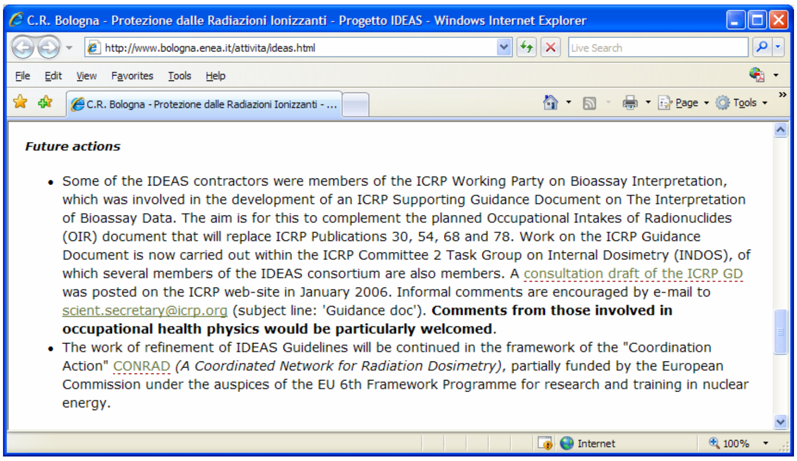
IDEAS / IAEA Intercomparison Exercise on Internal Dose Assessment

Intercomparison exercise on Internal Dose Assessment performed jointly by the International Atomic Energy Agency and the IDEAS project ("General Guidelines for the Evaluation of Incorporation Monitoring Data", carried out within the 5th EU Framework Programme).

Figure 4.8: SCK.CEN Report on IDEAS / IAEA Intercomparison Exercise

4.3 Future actions after the IDEAS project

The third part of the web page is related to the future actions: ICRP Working Party on Bioassay Interpretation and the link to the EURADOS (CONRAD WP5) (see Figure 4.9) which involves the development of an ICRP Supporting Guidance Document and the link to the ICRP web page devoted to the collection of comments and suggestions related to this item (see Figure 4.10).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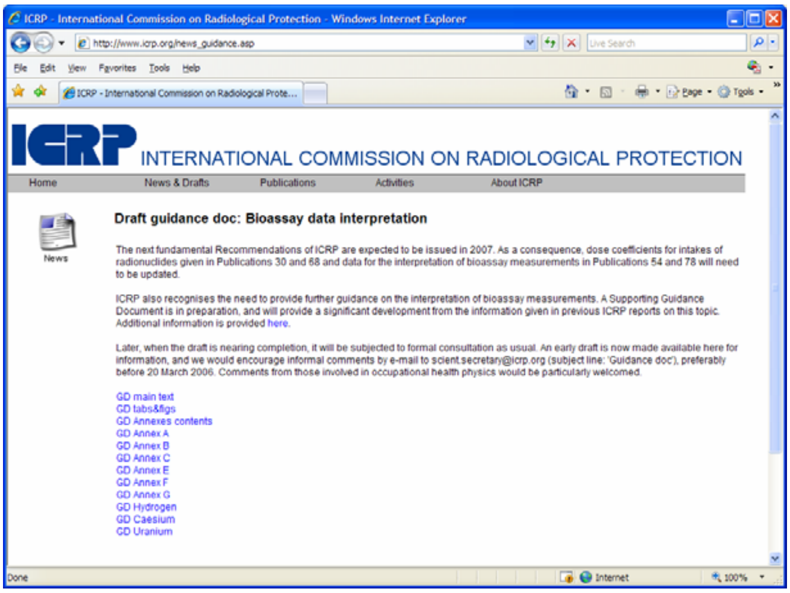
Future actions

- Some of the IDEAS contractors were members of the ICRP Working Party on Bioassay Interpretation, which was involved in the development of an ICRP Supporting Guidance Document on The Interpretation of Bioassay Data. The aim is for this to complement the planned Occupational Intakes of Radionuclides (OIR) document that will replace ICRP Publications 30, 54, 68 and 78. Work on the ICRP Guidance Document is now carried out within the ICRP Committee 2 Task Group on Internal Dosimetry (INDOS), of which several members of the IDEAS consortium are also members. A consultation draft of the ICRP GD was posted on the ICRP web-site in January 2006. Informal comments are encouraged by e-mail to scient.secretary@icrp.org (subject line: 'Guidance doc'). **Comments from those involved in occupational health physics would be particularly welcomed.**
- The work of refinement of IDEAS Guidelines will be continued in the framework of the "Coordination Action" CONRAD *(A Coordinated Network for Radiation Dosimetry)*, partially funded by the European Commission under the auspices of the EU 6th Framework Programme for research and training in nuclear energy.

Figure 4.9: Part 3: Link to ICRP and CONRAD web pages.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Draft guidance doc: Bioassay data interpretation

The next fundamental Recommendations of ICRP are expected to be issued in 2007. As a consequence, dose coefficients for intakes of radionuclides given in Publications 30 and 68 and data for the interpretation of bioassay measurements in Publications 54 and 78 will need to be updated.

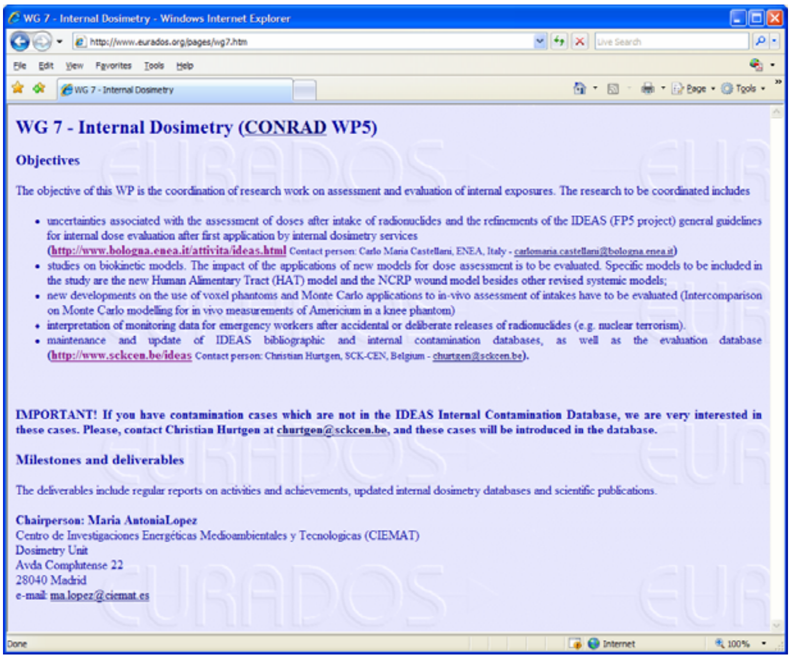
ICRP also recognises the need to provide further guidance on the interpretation of bioassay measurements. A Supporting Guidance Document is in preparation, and will provide a significant development from the information given in previous ICRP reports on this topic. Additional information is provided here.

Later, when the draft is nearing completion, it will be subjected to formal consultation as usual. An early draft is now made available here for information, and we would encourage informal comments by e-mail to scient.secretary@icrp.org (subject line: 'Guidance doc'), preferably before 20 March 2006. Comments from those involved in occupational health physics would be particularly welcomed.

GD main text
GD tabs&figs
GD Annexes contents
GD Annex A
GD Annex B
GD Annex C
GD Annex E
GD Annex F
GD Annex G
GD Hydrogen
GD Caesium
GD Uranium

Figure 4.10: ICRP web page related to the Guidance Document on Bioassay data interpretation

The link to the CONRAD WP5 is presented in Figure 4.11.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WG 7 - Internal Dosimetry (CONRAD WP5)

Objectives

The objective of this WP is the coordination of research work on assessment and evaluation of internal exposures. The research to be coordinated includes

- uncertainties associated with the assessment of doses after intake of radionuclides and the refinements of the IDEAS (FP5 project) general guidelines for internal dose evaluation after first application by internal dosimetry services (**http://www.bologna.enea.it/attivita/ideas.html** Contact person: Carlo Maria Castellani, ENEA, Italy - carlomaria.castellani@bologna.enea.it)
- studies on biokinetic models. The impact of the applications of new models for dose assessment is to be evaluated. Specific models to be included in the study are the new Human Alimentary Tract (HAT) model and the NCRP wound model besides other revised systemic models;
- new developments on the use of voxel phantoms and Monte Carlo applications to in-vivo assessment of intakes have to be evaluated (Intercomparison on Monte Carlo modelling for in vivo measurements of Americium in a knee phantom)
- interpretation of monitoring data for emergency workers after accidental or deliberate releases of radionuclides (e.g. nuclear terrorism).
- maintenance and update of IDEAS bibliographic and internal contamination databases, as well as the evaluation database (**http://www.sckcen.be/ideas** Contact person: Christian Hurtgen, SCK-CEN, Belgium - churtgen@sckcen.be).

IMPORTANT! If you have contamination cases which are not in the IDEAS Internal Contamination Database, we are very interested in these cases. Please, contact Christian Hurtgen at churtgen@sckcen.be, and these cases will be introduced in the database.

Milestones and deliverables

The deliverables include regular reports on activities and achievements, updated internal dosimetry databases and scientific publications.

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Dosimetry Unit
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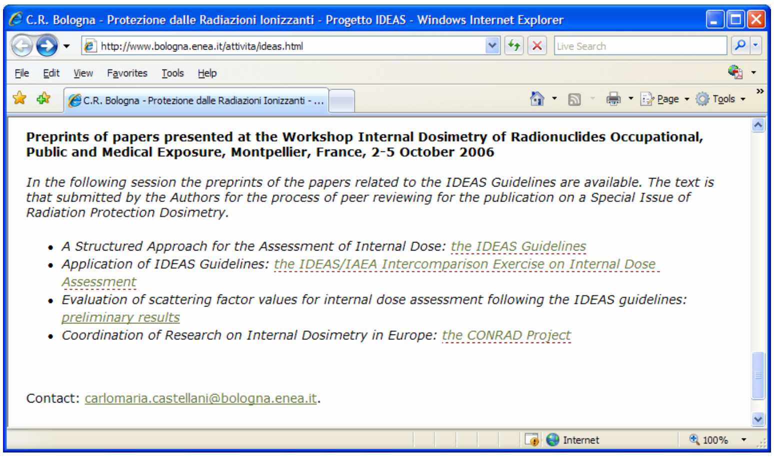
e-mail: ma.lopez@ciemat.es

Figure 4.11: CONRAD Work Package 5 web page

4.4 Preprints related to IDEAS activities

In the last part (Part 4) of the web page the preprints of four papers presented in the Workshop Internal Dosimetry of Radionuclides Occupational Public and Medical Exposure, held in Montpellier (France) from 2 to 5 October 2006 have been put for the free download. The papers (see Figure 4.12) are related to issues already performed during the IDEAS project (as the presentation of the IDEAS Guidelines or of the IDEAS/IAEA Intercomparison Exercise, see Figure 4.13, or the overall presentation of the work performed during the CONRAD Project (see Figure 4.14) or the evaluation of Scattering Factor values.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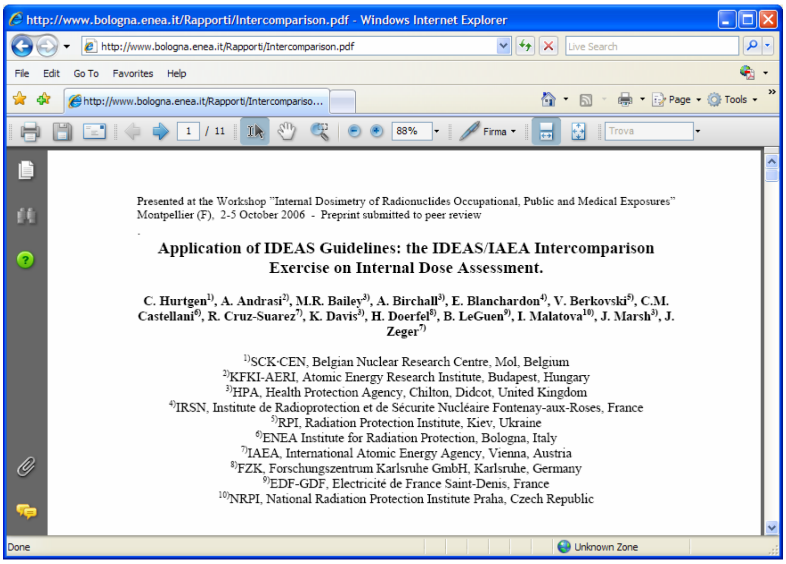
Preprints of papers presented at the Workshop Internal Dosimetry of Radionuclides Occupational, Public and Medical Exposure, Montpellier, France, 2-5 October 2006

In the following session the preprints of the papers related to the IDEAS Guidelines are available. The text is that submitted by the Authors for the process of peer reviewing for the publication on a Special Issue of Radiation Protection Dosimetry.

- *A Structured Approach for the Assessment of Internal Dose: the IDEAS Guidelines*
- *Application of IDEAS Guidelines: the IDEAS/IAEA Intercomparison Exercise on Internal Dose Assessment*
- *Evaluation of scattering factor values for internal dose assessment following the IDEAS guidelines: preliminary results*
- *Coordination of Research on Internal Dosimetry in Europe: the CONRAD Project*

Contact: carlomaria.castellani@bologna.enea.it.

Figure 4.12: Part 4: Link to download some pre-prints of papers related to the activities of IDEAS and CONRAD WP5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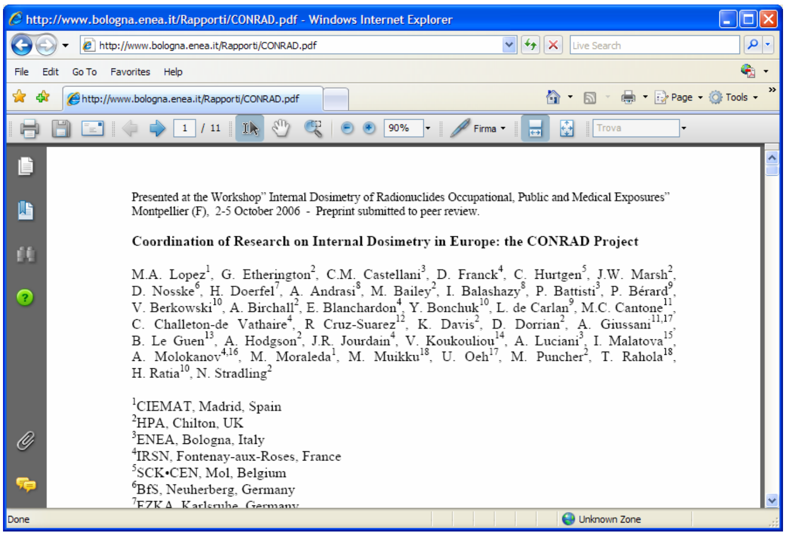
Presented at the Workshop "Internal Dosimetry of Radionuclides Occupational, Public and Medical Exposures"
Montpellier (F), 2-5 October 2006 - Preprint submitted to peer review

Application of IDEAS Guidelines: the IDEAS/IAEA Intercomparison Exercise on Internal Dose Assessment.

C. Hurtgen1), A. Andrasi2), M.R. Bailey3), A. Birchall3), E. Blanchardon4), V. Berkovski5), C.M. Castellani6), R. Cruz-Suarez7), K. Davis3), H. Doerfel8), B. LeGuen9), I. Malatova10), J. Marsh3), J. Zeger7)

1)SCK·CEN, Belgian Nuclear Research Centre, Mol, Belgium
2)KFKI-AERI, Atomic Energy Research Institute, Budapest, Hungary
3)HPA, Health Protection Agency, Chilton, Didcot, United Kingdom
4)IRSN, Institute de Radioprotection et de Sécurite Nucléaire Fontenay-aux-Roses, France
5)RPI, Radiation Protection Institute, Kiev, Ukraine
6)ENEA Institute for Radiation Protection, Bologna, Italy
7)IAEA, International Atomic Energy Agency, Vienna, Austria
8)FZK, Forschungszentrum Karlsruhe GmbH, Karlsruhe, Germany
9)EDF-GDF, Electricité de France Saint-Denis, France
10)NRPI, National Radiation Protection Institute Praha, Czech Republic

Figure 4.13: Paper on the IDEAS/IAEA Intercomparison Exercise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Presented at the Workshop" Internal Dosimetry of Radionuclides Occupational, Public and Medical Exposures"
Montpellier (F), 2-5 October 2006 - Preprint submitted to peer review.

Coordination of Research on Internal Dosimetry in Europe: the CONRAD Project

M.A. Lopez[1], G. Etherington[2], C.M. Castellani[3], D. Franck[4], C. Hurtgen[5], J.W. Marsh[2], D. Nosske[6], H. Doerfel[7], A. Andrasi[8], M. Bailey[2], I. Balashazy[8], P. Battisti[3], P. Bérard[9], V. Berkowski[10], A. Birchall[2], E. Blanchardon[4], Y. Bonchuk[10], L. de Carlan[9], M.C. Cantone[11], C. Challeton-de Vathaire[4], R Cruz-Suarez[12], K. Davis[2], D. Dorrian[2], A. Giussani[11,17], B. Le Guen[13], A. Hodgson[2], J.R. Jourdain[4], V. Koukouliou[14], A. Luciani[3], I. Malatova[15], A. Molokanov[4,16], M. Moraleda[1], M. Muikku[18], U. Oeh[17], M. Puncher[2], T. Rahola[18], H. Ratia[10], N. Stradling[2]

[1]CIEMAT, Madrid, Spain
[2]HPA, Chilton, UK
[3]ENEA, Bologna, Italy
[4]IRSN, Fontenay-aux-Roses, France
[5]SCK•CEN, Mol, Belgium
[6]BfS, Neuherberg, Germany

Figure 4.14: Paper presenting the CONRAD WP5 activities on internal dosimetry

4.5 Further actions

In the near future the ENEA / IDEAS web page will be updated with the following areas for download:

- The CONRAD deliverable related to refinement of IDEAS Guidelines inside the work of WP5.1.
- The pdf files of the three presentations to the Scientific Symposium *Achievements of the CONRAD Coordination Action* connected to the EURADOS

  - ➢ *Internal dosimetry: towards harmonization and coordination of research* by Maria Antonia Lopez (CIEMAT , E).
  - ➢ *Internal dose assessements: Uncertainty studies and update of IDEAS Guidelines and Databases* by James Marsh (HPA-RPD, UK).
  - ➢ *Development, implementation and quality assurance of biokinetic models within CONRAD* by Dietmar Nosske (BfS, D).

- ❖ A new version of the IDEAS Guidelines with all refinements prepared during WP5.1.

An area devoted to a foreseen EURADOS Advanced Training Course on Internal Dose Assessment will be also present.

4.6 Conclusions on web page

The aim of the set up of the ENEA / IDEAS web page is to provide updated documents and tools to perform internal dose assessment on the basis of the developed IDEAS Guidelines.

The web page is linked to the most complete collection of references and internal contamination cases databases maintained and updated periodically by the SCK.CEN representative (Christian Hurtgen) which collects and makes available new or unpublished internal contamination cases provided by experts all over the world (churtgen@sckcen.be). A source of dose assessment examples (Evaluation of Cases database) is also available.

Several documents can be downloaded:

- the description of the reference methodologies presented by the IDEAS Guidelines,
- the results of the last IDEAS / IAEA intercomparison exercise with explanations and detailed descriptions of internal contamination cases,
- presented papers related to the refinements and updating of the guidelines

The link with the most updated web pages related to the refinement and application of methodologies for internal dose assessment is also present. This makes the web page the most complete and useful source of information for internal dose assessment available on the net.

The use of this source of information is mainly addressed to update professional dose assessment methodologies, to perform research on internal biokinetic modeling via real contamination cases, to promote training activities in internal dose assessment especially for new beginners in the field.

5 EFFECTIVE AMAD EVALUATION

5.1 Introduction

Inside the IDEAS Guidelines indication has been introduced on the evaluation of an "effective AMAD" inferred *a posteriori* on the base of early feces and lung data. The effect of AMAD in fact is to determine the relative amounts deposited (a) in the upper respiratory tract which, when not absorbed into blood, is rapidly cleared to the feces of few days, (b) in the lower respiratory tract, which is slowly cleared from the lung. The ratio of the cumulative fecal excretion of the first three days to the lung activity at day 3 after incident has been evaluated as a function, monotonic crescent, of the effective AMAD in the ICRP Supporting Guidance 3 [20].

In Figure 6.7 of report FZKA7243 [2], the figure for the behaviour, in function of effective AMAD, of the ratio of ^{241}Am cumulative fecal excretion from 1 to 3 days after inhalation to the lung activity at day 3, has been reported. The range of effective AMAD values is 1 to 10 µm. Two curves related to absorption type M, as default value, and type S (in case of contemporaneous inhalation of non soluble mixture of Pu and Am isotopes) are reported.

In the present paragraph it is intended to expand this methodology for evaluation of ^{235}U and ^{60}Co.

In case of the ^{60}Co it has been used as the whole body activity at day 10 after inhalation as indication of the amount present in the low lung. At this date after the incident the components present in the ET1 region and in the GI tract can be considered emptied and the measured activity can be sufficiently considered representing the activity deposited in the deep lung.

5.2 Methodologies

For the evaluation of the function of the ratio of the cumulative fecal excretion to the activity in the lung the code IMBA Professional Plus^{TM} [21] has been used. The values of the ratio have been evaluated for 27 points within the range 0.1 – 10 µm AMAD. The default material values are: Geometric standard deviation calculated on the base of the equation reported in ICRP 66 [22] report at paragraph D13.4 and Fig. D.39 i.e.

$$\sigma_g = 1 + 1.5 \cdot \left(1 - \frac{1}{\left(100 \cdot AMTD^{1.5} + 1\right)}\right)$$

with AMTD, activity median thermodynamic diameter defined as:

$$AMTD = AMAD\sqrt{\frac{\chi\rho_0}{\rho} \cdot \frac{C(AMAD)}{C(AMTD)}}$$

with $\chi = 1.5$ (dynamic shape factor) and ρ (particle density) = 3 g/cm^3 of the real particle and ρ_0 the unit density value = 1 g/cm^3

The function C(d) is the slip correction factor with the expression:

$$C(d) = 1 + \frac{\lambda}{d} \cdot \left(2.514 \cdot +0.8000 \cdot \exp\left(-0.55 \cdot \frac{d}{\lambda} \right) \right)$$

with λ = 0.0683 µm, mean free path of air molecules at 37 ° C

IMBA Professional Plus^{TM} performs automatically the evaluation of the σg
The values of σg range from 1.85 for 0.1 µm AMAD to 2.499 for 10 µm AMAD.

Three radionuclides have been considered for the evaluations: ^{241}Am for which already graphical indications are available, ^{60}Co for which evaluations on cases with f_1=f_r=0 have already been evaluated [23] and ^{235}U which can be easily detected in lung. The evaluations have been done for those default compounds that are not absorbed in the respiratory tract (typically absorption types M and S).

5.3 Results

In Figure 5.1 the behaviour of the ratio of the cumulative feces from day 1 to day 3 to the lung measurement on day 3 is presented.

For comparison with the previous figure presented in IDEAS Guidelines report, the same values are also reported on a linear effective AMAD scale.

In the case of ^{60}Co the evaluated ratio is the cumulative fecal excretion over the first three days to the whole body retention on day 10. The values are evaluated for absorption types M (related f1 equal to 0.1) and S (related f1equal to 0.05). For opportune comparison the value of the ratio calculated for type S parameters and fr = f1 = 0 has been also presented in Figures 5.3 and 5.4.

For the ^{235}U the evaluation is based as for ^{241}Am, on the values of cumulative fecal excretion and the value of lung activity on day 3 (Figure 5.5 and Figure 5.6).

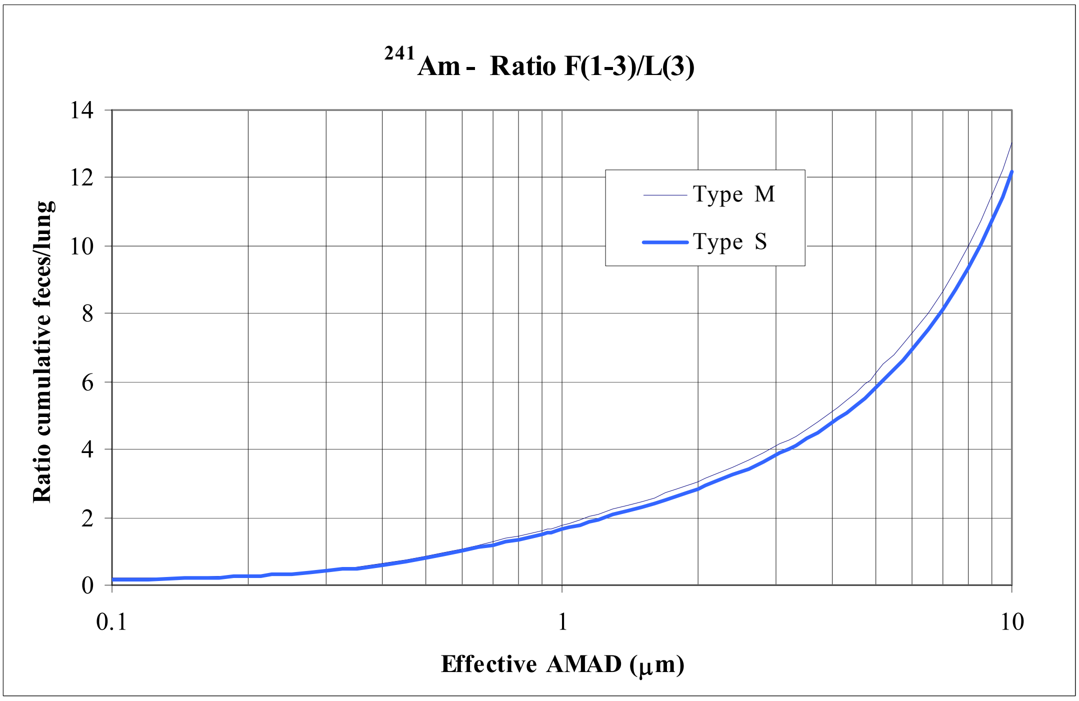

Figure 5.1: Ratio cumulative feces to lung measurements in function of effective AMAD, for ^{241}Am, absorption types M and S

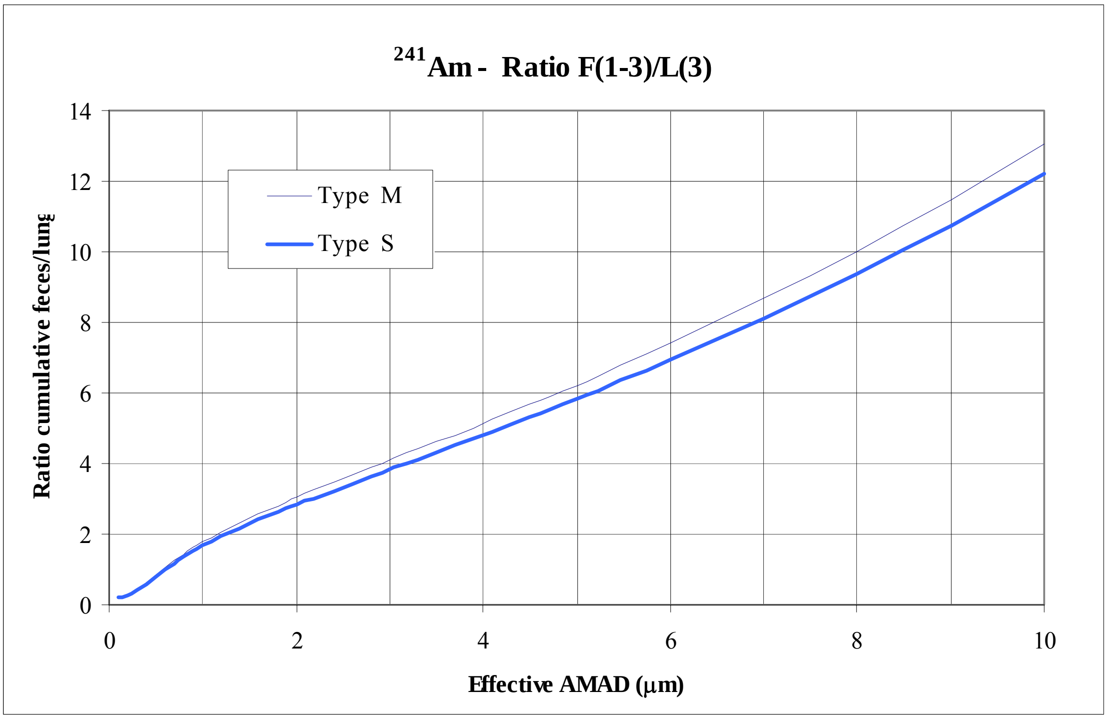

Figure 5.2: Ratio cumulative feces to lung measurements in function of effective AMAD, for ^{241}Am, absorption types M and S, AMAD linear scale

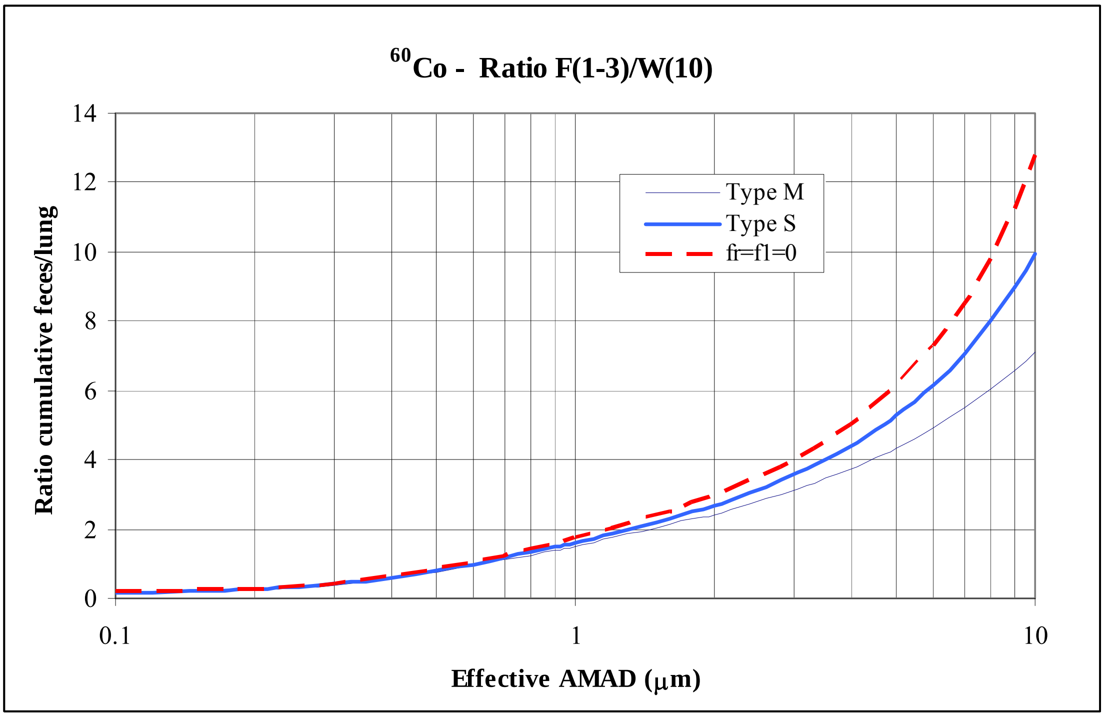

Figure 5.3 : Ratio cumulative feces to whole body (W) measurements for ^{60}Co , absorption types M and S, and S with fr=f1=0.

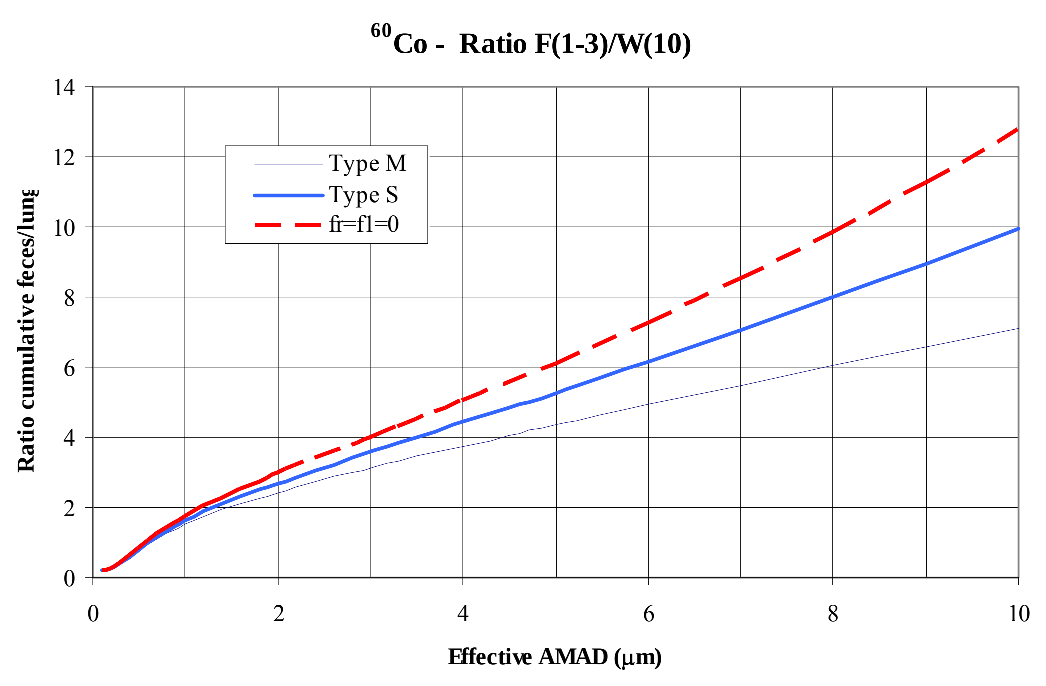

Figure 5.4: Ratio cumulative feces to whole body (W) measurements for ^{60}Co , absorption types M and S, and S with fr=f1=0, linear AMAD scale.

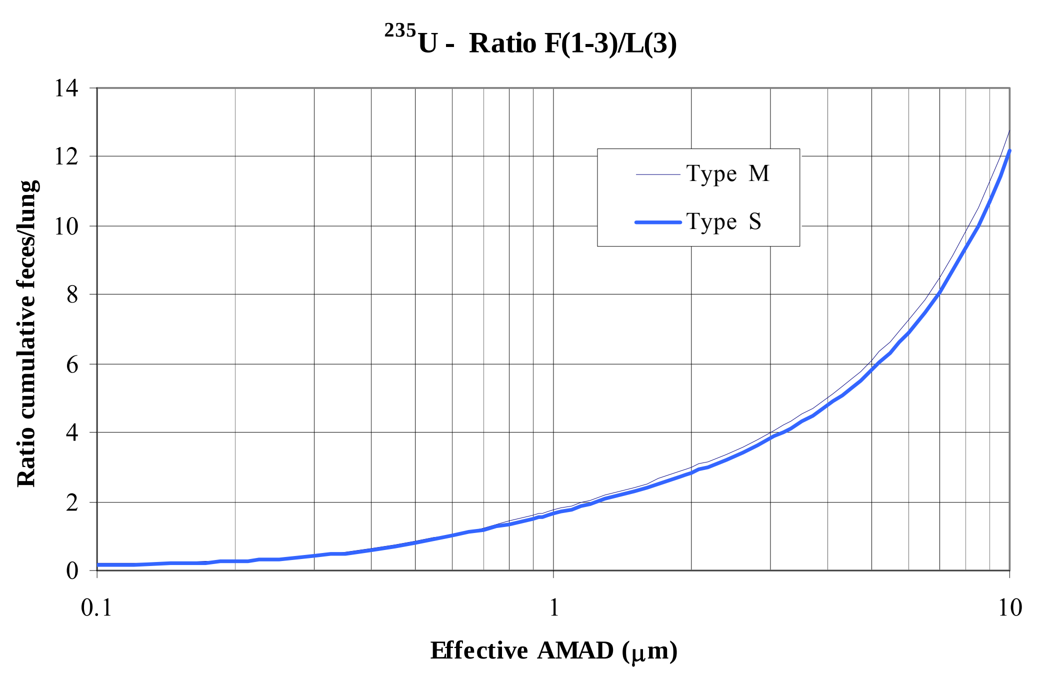

Figure 5.5: Ratio cumulative feces to lung measurements in function of effective AMAD, for ^{235}U, absorption types M and S

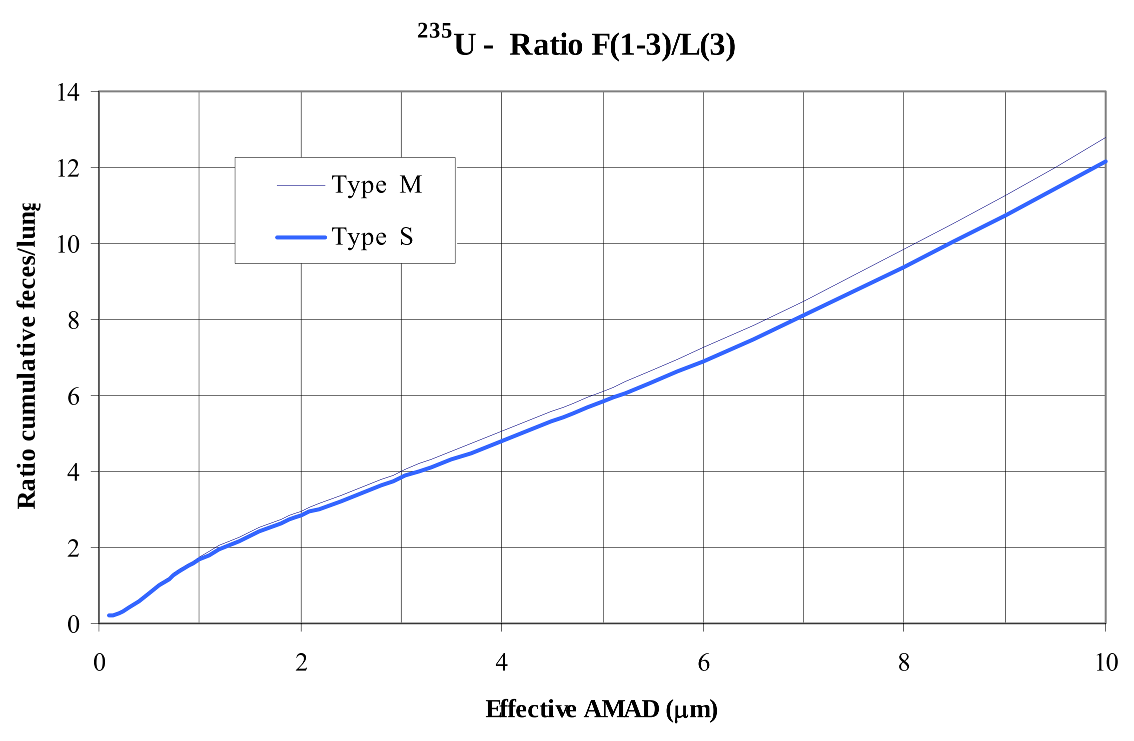

Figure 5.6. Ratio cumulative feces to lung measurements in function of effective AMAD, for ^{235}U , absorption types M and S, linear AMAD scale

5.4 Polynomial fitting of the data

The 27 values of the ratio were fitted using as independent parameter the effective AMAD with a polynomial of third degree with known term $y = y0+a*x+b*x^2+c*x^3$. The fitting has been performed using the software SigmaPlot^{TM} by means of not linear interpolation. A t-test has been preformed on each parameter value to estimate his contribution to predict the dependent variable on the base of his standard error.

The t statistic test has been used: the null hypothesis is that the coefficient of the independent variable is zero, that is, the independent variable does not contribute to predicting the dependent variable. t is the ratio of the regression coefficient to its standard error. You can conclude from large t values that the independent variable can be used to predict the dependent variable (for example, that the coefficient is not zero).

The probability value (P Value) calculated for t using the degrees of freedom equal to the number of data minus the number of calculated parameters, with a two tail test is also evaluated by the software. The P value is the probability of being wrong in concluding that the coefficient is not zero (i.e. the probability of falsely rejecting the null hypothesis, or committing a Type I error, based on t). The smaller the P value, the greater is the probability that the coefficient is not zero. Here it has been assumed that the independent variable can be used to predict the dependent variable, when $P < 0.05$.

In all cases, except for ^{60}Co type M and ^{60}Co type S, the calculated P value for y0 is greater than 0.05 and so it has been concluded that the y0 value is statistically equal to zero. In all the other cases the fitting has been repeated using a function of the type $y = a*x+b*x^2+c*x^3$, a polynomial of third degree without the term at degree zero.

The parameter value, the asymptotic standard error of the parameter and the corresponding P value are displayed in Tables 1 to 7. Tables 5.1 and 5.2 refer to ^{241}Am, tables 5.3, 5.4, and 5.5 to ^{60}Co and tables 5.6 and 5.7 to ^{235}U.

Table 5.1: Fitted parameters of the polynomial fitting of ^{241}Am Type M.

	Initial fitting			Final fitting without term at degree zero		
Coefficient	Fitted value	Standard error	P value	Fitted value	Standard error	P value
Y0	0.0910	0.0542	0.1070	-	-	-
A	1.6781	0.0630	<0.0001	1.7665	0.0358	<0.0001
B	-0.1367	0.0166	<0.0001	-0.1567	0.0120	<0.0001
C	0.0100	0.0012	<0.0001	0.0112	0.0009	<0.0001

Table 5.2: Fitted parameters of the polynomial fitting of ^{241}Am Type S.

	Initial fitting			Final fitting without term at degree zero		
Coefficient	Fitted value	Standard error	P value	Fitted value	Standard error	P value
Y0	0.0910	0.0500	0.0822	-	-	-
A	1.5653	0.0581	<0.0001	1.6537	0.0333	<0.0001
B	-0.1270	0.0153	<0.0001	-0.1470	0.0112	<0.0001
C	0.0093	0.0011	<0.0001	0.0105	0.0009	<0.0001

Table 5.3: Fitted parameters of the polynomial fitting of ^{60}Co Type M.

	Initial fitting		
Coefficient	Fitted value	Standard error	P value
Y0	0.1392	0.0510	0.0119
A	1.3825	0.0592	<0.0001
B	-0.1436	0.0156	<0.0001
C	0.0076	0.0011	<0.0001

Table 5.4: Fitted parameters of the polynomial fitting of ^{60}Co Type S.

	Initial fitting		
Coefficient	Fitted value	Standard error	P value
Y0	0.1084	0.0508	0.0436
A	1.5015	0.0590	<0.0001
B	-0.1310	0.0156	<0.0001
C	0.0081	0.0011	<0.0001

Table 5.5: Fitted parameters of the polynomial fitting of ^{60}Co Type S, with fr = f1 = 0.

	Initial fitting			Final fitting without term at degree zero		
Coefficient	Fitted value	Standard error	P value	Fitted value	Standard error	P value
Y0	0.0967	0.0513	0.0723	-	-	-
A	1.6347	0.0584	<0.0001	1.7267	0.0337	<0.0001
B	-0.1295	0.0155	<0.0001	-0.1501	0.0115	<0.0001
C	0.0094	0.0011	<0.0001	0.0107	0.0009	<0.0001

Table 5.6: Fitted parameters of the polynomial fitting of ^{235}U Type M.

	Initial fitting			Final fitting without term at degree zero		
Coefficient	Fitted value	Standard error	P value	Fitted value	Standard error	P value
Y0	0.0914	0.0527	0.0960	-	-	-
A	1.6432	0.0612	<0.0001	1.7321	0.0349	<0.0001
B	-0.1335	0.0161	<0.0001	-0.1536	0.0117	<0.0001
C	0.0098	0.0011	<0.0001	0.0110	0.0009	<0.0001

Table 5.7: Fitted parameters of the polynomial fitting of ^{235}U Type S.

	Initial fitting			Final fitting without term at degree zero		
Coefficient	Fitted value	Standard error	P value	Fitted value	Standard error	P value
Y0	0.0908	0.0500	0.0822	-	-	-
A	1.5631	0.0580	<0.0001	1.6513	0.0333	<0.0001
B	-0.1268	0.0153	<0.0001	-0.1468	0.0112	<0.0001
C	0.0093	0.0011	<0.0001	0.0105	0.0009	<0.0001

In Table 5.8 the summary table of the fitting parameter values has been reported. In the ratio column the indication F(1-3) indicates the cumulative fecal excretion during the first three days. L3 indicates the lung measurement on the day 3 after accident. W10 indicates the whole body measurement performed on day 10 after accident. In the same table NS indicates that the value has not been fitted as it is not significantly different from zero. R indicates the correlation coefficient. As can be seen the values are always greater than 0.99, indicating very good fit.

Table 5.8: Summary table of the fitting parameter values of the function ratio F(1-3)/L3 in function of effective AMAD

Radio-nucide	Absorption Type	f1	Ratio	y0	a	b	c	R
^{241}Am	M	0.0005	F(1-3)/L3	NS	1.7665	-0.1567	0.0112	0.9995
^{241}Am	S	0.0005	F(1-3)/L3	NS	1.6537	-0.1470	0.0105	0.9995
^{60}Co	M	0.1	F(1-3)/W10	0.1392	1.3825	-0.1436	0.0076	0.9988
^{60}Co	S	0.05	F(1-3)/W10	0.1084	1.5015	-0.1310	0.0081	0.9994
^{60}Co	S	fr =f1=0	F(1-3)/W10	NS	1.7267	-0.1501	0.0107	0.9995
^{235}U	M	0.02	F(1-3)/L3	NS	1.7321	-0.1536	0.0110	0.9995
^{235}U	S	0.002	F(1-3)/L3	NS	1.6513	-0.1468	0.0105	0.9995

In the case of a three parameter fitting (without value at degree zero, 5 cases) the values for the parameters are very similar from one case to another. Also the standard error is always about 2% for the a coefficient, 7.6% for the b coefficient and 8.4% for the c coefficient.

In the two cases of Co, the y0 coefficient is affected by an uncertainty, expressed as standard error, equal to 37-47% of the value. The other parameters have uncertainty about 4, 12 and 14% respectively for the coefficients a, b and c.

When available early feces and lung (or whole body) data the fitted functions can be used to infer the effective AMAD value. Using the uncertainty in the coefficients the range of values that can be assumed for the effective AMAD can be estimated.

6 GUIDELINES FOR THE APPLICATION OF NCRP WOUND MODEL

6.1 Introduction

During the development of the CONRAD Task 5.1 the NCRP made available a final draft for the application of the model related to the wound contamination. Inside the CONRAD Group it has been decided to use the proposed model to evaluate some cases present inside the IDEAS Internal Contamination Database with the aim of developing a procedure to be introduced inside the IDEAS Guidelines.

Description of the NCRP wound model

From the paper of Durbin and Guilmette [24] the structure of the model is composed by 5 compartments linked together with a first order kinetics (see Figure 6.1). They have been named: Soluble, Colloidal and Intermediate State (CIS), Particles, Aggregates and Bound State (PABS), Trapped Particles and Aggregates (TPA), and Fragment. The whole structure of the model is presented in Figure 6.1.

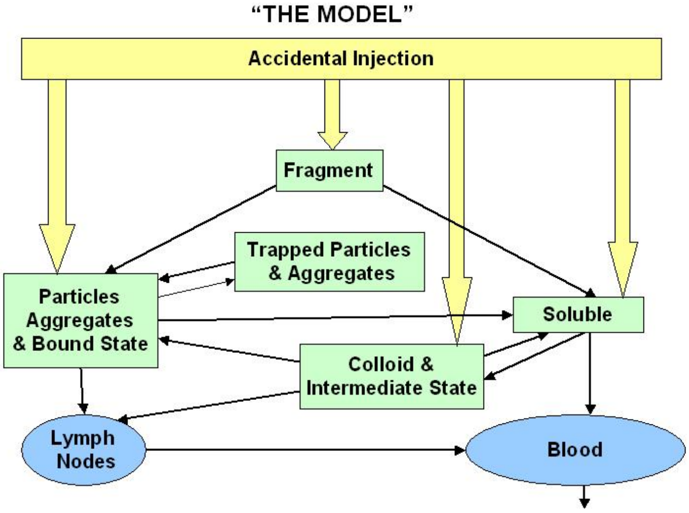
"THE MODEL"
Accidental Injection
Fragment
Trapped Particles & Aggregates
Particles Aggregates & Bound State
Soluble
Colloid & Intermediate State
Lymph Nodes
Blood

Figure 6.1 : General structure of the NCRP wound model

These compartments are designed to describe some physical or chemical state of the radionuclide. The overall structure of the model is intended to describe in a general way both soluble and insoluble materials. The transfer of the radioactive material from the wound is performed via the Blood compartment for the soluble material and Lymph nodes (LN) for particulates. The Blood compartment is the compartment that links the wound model to the systemic model of each radioelement. The behaviour of a radionuclide that reaches the blood is the same as that of a radionuclide that is injected.

From the point of view of the mechanisms that determine the behaviour of a radionuclide in a wound it is possible to indicate the solution chemistry for soluble materials (in particular the tendency to hydrolyze) that often determines its persistence in the wound. For insoluble materials other mechanisms such as phagocytosis, and fibrous tissue encapsulation play the major role.

Different sub-models (categories) have been thus indicated in the draft report in relationship to the chemical and physical status of the material.

For soluble compounds the chemical behaviour is the most important parameter. Four categories of retention were defined for radionuclides present in a wound initially in soluble form: Weak, Moderate, Strong and Avid. They refer generally to the magnitude of persistent retention in the wound. For these Soluble categories the general model as depicted in Figure 6.1, is reduced to 3 compartments and there is no outcome from the LN towards the blood (see Figure 6.2).

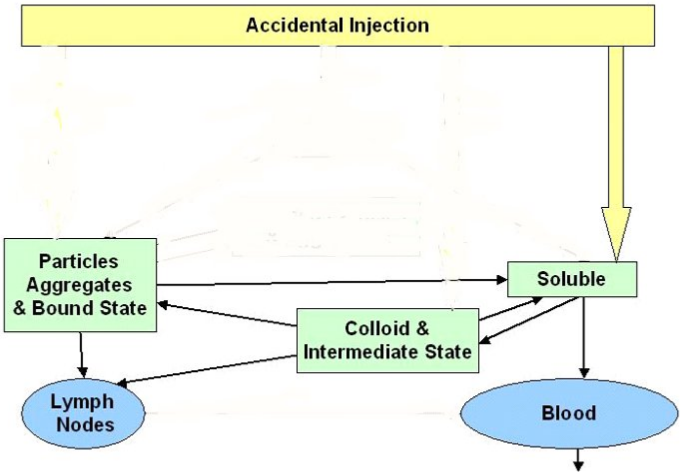
Accidental Injection
Particles Aggregates & Bound State
Soluble
Colloid & Intermediate State
Lymph Nodes
Blood

Figure 6.2: The Soluble model

Regarding the persistence in the wound three terms exponential functions have been indicated in the draft report for the four categories of soluble compounds. In Figure 6.3 the reference retention behaviours in wound are presented.

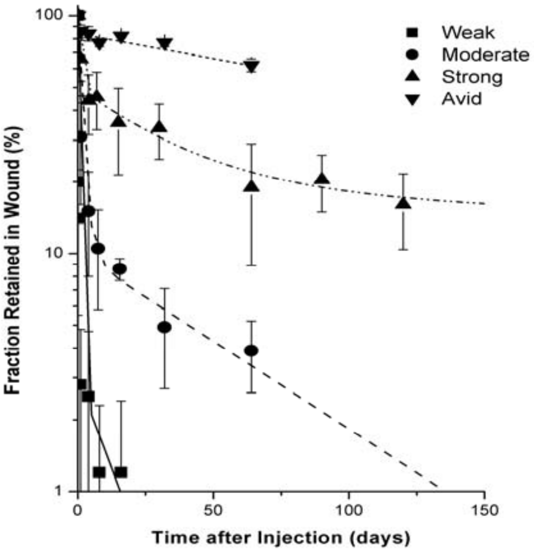

Figure 6.3: Default retention in wound for reference soluble materials.

For radioactive solids the modeling of insoluble compounds in wounds is much more difficult due to the paucity of human data. The presence of biologically recognizable particulate material in a wound has the potential to elicit a foreign-body reaction, which usually begins with an inflammatory reaction.

The behaviour of particulate radionuclides in wounds has been grouped into three main categories, which are distinct based on the physical properties of the deposited material and on retention pattern.

The Colloid category consists of radionuclides that exist as frank colloidal material prior to deposition, and typically have small fractions of the deposited amount that clear rapidly from the wound site. For this category the general model reduces as that presented in Figure 6.4.

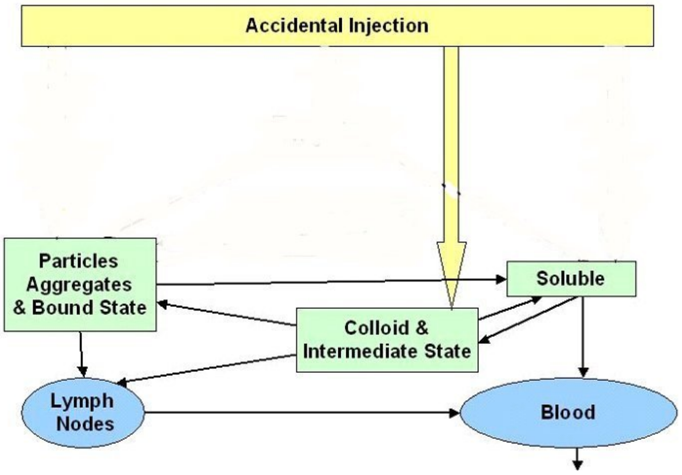
Accidental Injection
Particles Aggregates & Bound State
Soluble
Colloid & Intermediate State
Lymph Nodes
Blood

Figure 6.4: The Colloid Model

The Particle category represents material, typically relatively insoluble, whose individual physical sizes are ≤ 20 µm. This upper limit generally bounds the size of particles that can be phagocytized by tissue macrophages or can be moved to lymphatics via fluid flows to collecting lymph nodes. In this case the model reduces to that presented in Figure 6.5.

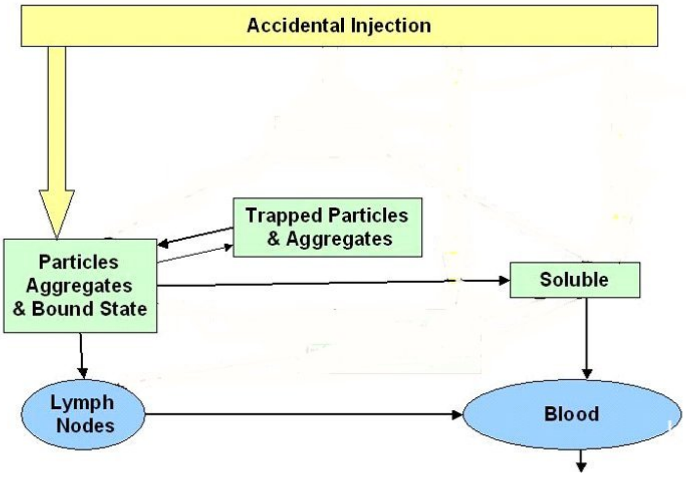
Accidental Injection
Trapped Particles & Aggregates
Particles Aggregates & Bound State
Soluble
Lymph Nodes
Blood

Figure 6.5: The Particle model

The Fragment category includes large particles and fragments whose size and/or quantity of material are sufficient to cause a foreign body tissue reaction, in which fibrous connective tissue encapsulates the deposited material, and is thought to retard the physical and chemical movement of material from the wound site. The Fragment model is presented in Figure 6.6.

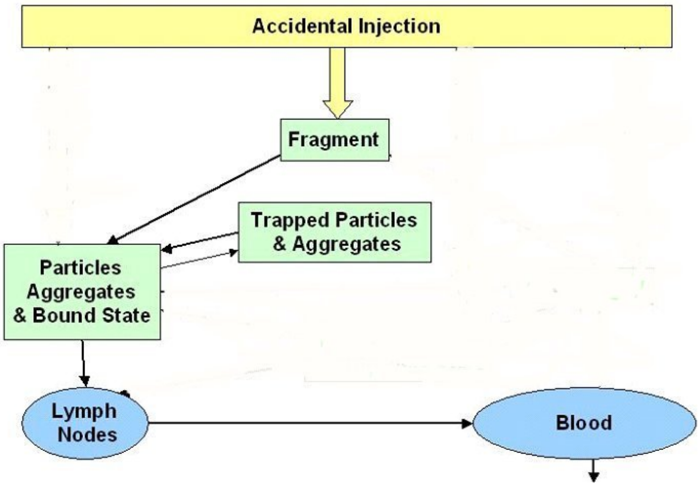
Accidental Injection
Fragment
Trapped Particles & Aggregates
Particles Aggregates & Bound State
Lymph Nodes
Blood

Figure 6.6: The fragment model

The equations of retention in the wound as three-exponential sum have been provided also for the other models. The most consistent observation for the retention of these categories of radioactive solids in wounds is the very long retention of the majority of the deposited material. This long-term retention is surmised to be due to the intrinsic insolubility of the forms of materials that have been studied, mainly Pu and U, and the foreign-body encapsulation phenomenon, although the latter may not be required for long retention. In Table 6.1 the default values for the transfer rates for soluble and insoluble materials are presented.

Table 6.1: Default transfer rates for the various categories

	Default transfer rates for the wound model for the various categories of radionuclides in wounds				
	Transfer rate (d^{-1})				
Transfer	Soluble Strong	Soluble Avid	Colloid	Particle	Fragment
Soluble to Blood	0.67	7.0	0.5	100	-
Soluble to CIS	0.6	30	2.5	-	-
CIS to Soluble	0.024	0.03	0.025	-	-
CIS to PABS	0.01	10	0.05	-	-
CIS to LN	2×10^{-5}	2×10^{-5}	2×10^{-3}	-	-
PABS to Soluble	0.0012	0.005	0.0015	2×10^{-4}	0
PABS to LN	2×10^{-5}	2×10^{-5}	4×10^{-4}	3.6×10^{-3}	0.004
PABS to TPA	-	-	-	0.04	0.7
TPA to PABS	-	-	-	0.0036	0.0005
LN to Blood	-	-	0.03	6×10^{-4}	0.03
Fragment to Soluble	-	-	-	-	0
Fragment to PABS	-	-	-	-	0.008

6.2 Application of the wound model to plutonium cases.

In relation to the application of the wound model for the ^{239}Pu isotope as presented by a paper of N. Ishigure [25] in the Montpellier 2006 Workshop, it has been agreed to perform the evaluation of those cases inside the IDEAS Internal Contamination Database [] which does not present problems of chelation therapy with DTPA.

At a selection in the database for intake from wound, the following cases were found: number 42, 61, 234, 235, 236, 237 and 238.

The cases were evaluated following the procedure indicated in the IDEAS Guidelines[26] in particular for the evaluation of the fitting. The measured daily urine excretion values have been compared with the prediction of a specific wound model (for the selected category) linked with the ICRP 67 [27] plutonium systemic model.

In accordance with the outcome of the work related to the refinement of evaluation of SF values reported in reference [7] for the fitting evaluation to each urine daily excretion datum an SF value of 1.7 has been given. To have a conservative approximation of the order of magnitude of the committed effective doses connected with the evaluation of the deposited activity in the wound, assessed on the base of the urine data, the dose coefficient for injection [0.493 mSv/Bq], as indicated by N. Ishigure in reference [], has been used.

Case 42.

It is one of the selected Hanford cases, presented in a paper of Bramson et al. in 1972 [28]. It is a case of internal contamination of Pu with a single deposition in the wound, and no use of DTPA. The date of the event is 28/3/1958. Fifty-eight urine values spanning from 3 up to 2338 days after accident are available. The indication of the radioisotope as “Pu” has been considered as ^{239}Pu. The behaviour of the data is decreasing from values of about 800 mBq/d to values of 6-7 mBq/d. The wound model category soluble strong has been used.

Using the excretion values per unit intake for the wound model connected to the ICRP 67 model one obtains the values of 440 Bq for the deposited activity in wound. The p-value of the fitting [] is 0.0012, less than 0.05, so the fit is rejected by the IDEAS Guidelines requirement. At a deeper evaluation of the data, the test for rogue data applied to the excretion value at 1944 days after the incident, indicates that the value is a rogue data (less than a factor of SF^3 in relationship to the trend of the other data). Not considering the value at 1944 days the fit of the data is accepted (p-value = 0.40), the estimated deposited activity in the wound is equal to 465 Bq and the committed effective dose is 229 mSv. In
Figure 6.7 the behaviour of the experimental data and the fitting are presented.

As the fitting is not rejected it is possible to consider that the general behaviour of soluble strong can adequately describe the trend of the data.

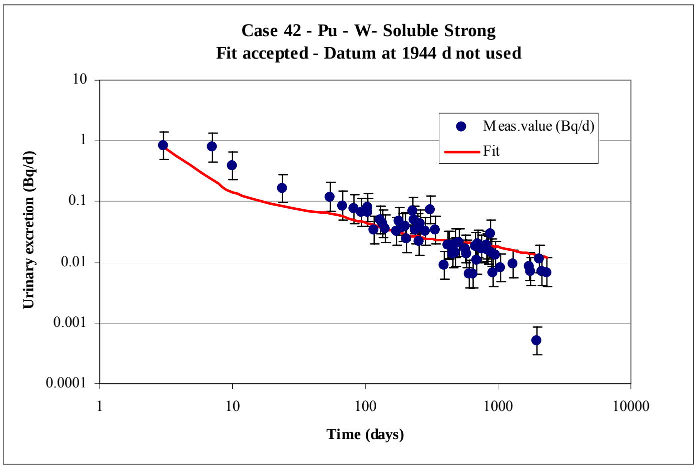

Figure 6.7 : Case 42: experimental data and fitting with wound model. Soluble Strong.

Case 61.

This case deals with a paper of 1980 of Parkinson [29], in which a person is subjected to an experiment to evaluate the excretion function for Cm compounds. An acidic solution of $^{244}Cm(NO_3)_3$ was used.

He is subjected to a puncture wound to the finger to evaluate the excretion phase of the curium. Seven daily urine data are available from 1 to 149 days. The behaviour of the urinary daily excretion data is decreasing from 270 to 1 mBq/d. The interpretation with the ^{239}Pu Soluble strong wound model provides a reasonable fit (p-value = 0.20). The evaluation necessitates to be done again with the correct model of Cm. The indication of the general wound model as soluble strong permits to reproduce the observed general behaviour, as can be seen in Figure 6.8. The systemic behaviour of Cm is indicated as equal to that of Am in publication ICRP 71 [30] and not to Pu. The main differences in respect to the Pu model are: different partitioning of activity between skeleton and liver (ratio 3:5 instead of 5:3 for Pu), only one liver compartment in comparison of the two compartments indicated for Pu, no ST1 to bladder path for Cm, different physical half-time (18.1 y in respect to 2.41 x 10^4 y for ^{239}Pu).

Also in this case the general trend related to the soluble strong category can explain the behaviour of the experimental data.

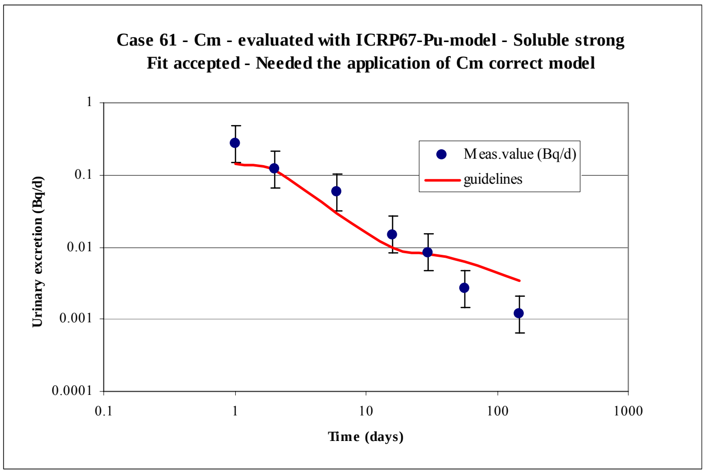

Figure 6.8: Case 61: Cm experimental data and fitting with Pu wound model Soluble Strong

Case 234

It is a case, occurred on 10 March 1961 and reported by Falk [31] as case 502, related to a cut of the right hand ring finger of a Pu machinist while machining plutonium metal. The laceration was approximately 3.8 cm long and may have included carbon tetrachloride or machine cutting oil along with Pu contamination.

Two excisions were performed. On day one the estimated contamination (about 6700 Bq) was reduced to 5500 Bq; on day 358, a second excision was performed to remove a nodule at wound site: 1300 Bq were estimated to remain at wound site after excision.

Forty-four urine data are available from day 1 up to about 40 year after incident and are reported in Figure 6.9.

The behaviour of the urine excretion is inside one order of magnitude (during the 40 years after incident) and this could indicate a colloid behaviour, also considering the simultaneous deposition in the wound of machine oil. The fit with the colloid wound model is accepted by the IDEAS requirement (p-value = 0.08); the deposited activity in the wound is estimated to be 1907 Bq which has the same order of magnitude of the value of 1300 Bq estimated on 3 March 1962 and 1570 ± 300 Bq estimated on 21 August 2001. Using the injection dose coefficient, as suggested in reference [], this corresponds to 0.94 Sv committed effective dose.

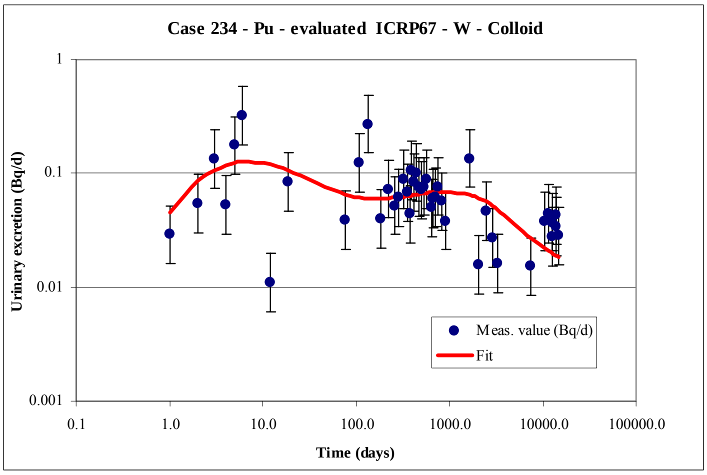

Figure 6.9 : Case 234: Experimental data and fitting with Pu wound model Colloid

Case 235

This case is related to a puncture wound of hand of a Pu machinist at the dorsal face of the thumb. The case has been reported as case 620 in the paper of Falk []. An ellipse of skin about the wound and a portion of subcutaneous tissue were excised. One blood vessel was legated and the skin was closed with silk sutures. The remaining contamination estimated after excision in 2 May 1962 is about 410 Bq. A wound count on 9 Nov.1995 (i.e. 33 years after the incident) gives a value of 190 ± 42 Bq.

Twenty-four urine values are available in a time range of 33.5 years.

The behaviour of the data is decreasing from values of 2.45 Bq/d at day 6 down to 5 mBq/d at day 2192 suggesting a soluble strong behaviour. On the other hand the presence of an activity in the wound that remains half of the original value, more than 33 years after the incident, indicates an insoluble behaviour or an avid retention in wound.

The evaluation of the deposited amount in the wound has been performed in different steps.

The first attempt is to evaluate if the data at day 2192 (5.2 mBq/d) is a rogue data. The test presented in the IDEAS Guidelines (more than a factor of SF^3 below the trend of other data) indicates that the value actually is a rogue datum, so in all the next evaluations on deposited activity the value has not been used. The first evaluation has been done with the soluble strong category. The fit has been rejected by the IDEAS criterion (p-value = 0.003), as can be seen in Figure 6.10.

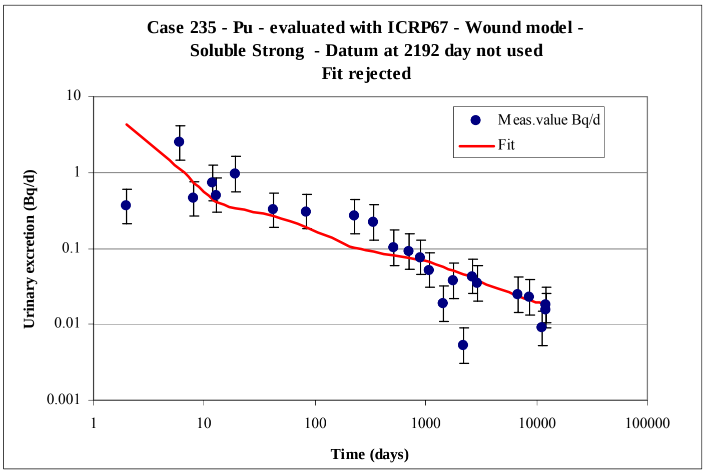

Figure 6.10: Case 235: Experimental data and fitting with Pu wound model Soluble Strong

The second attempt was made using the colloid category. The fit resulted even worse (p-value = 1E-10). The Figure 6.11 presents the fitting.

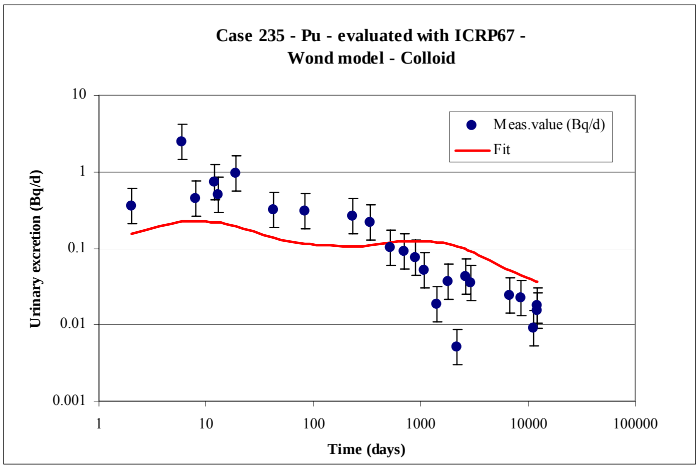

Figure 6.11: Case 235: Experimental data and fitting with Pu wound model Colloid

The third attempt is made fitting the data with the NCRP default Soluble Avid category. The fit is not accepted as the resulted p-value is equal to 7E-9. In Figure 6.12 the fitting using the Avid behaviour is presented.

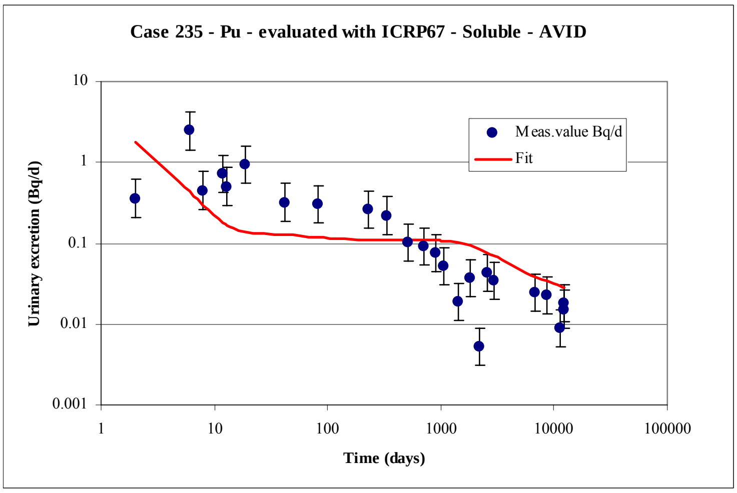

Figure 6.12 Case 235: Experimental data and fitting with Pu wound model. Soluble Avid

So the soluble strong behaviour seems to be the less bad fit of the urinary excretion following this incident.

The fourth attempt was made using the Soluble strong category but reducing by a factor of 10 the overall clearance rate going out of the compartment “soluble”, that is by default equal to 1.27 d^{-1}, while maintaining the partitioning fractions 0.5276 for the path Soluble ⇒ Blood and 0.4724 for the path Soluble ⇒ CIS. The final value of the overall clearance rate used in the evaluation is thus 0.127 d^{-1}. This decrease of parameters could be related to a slower transfer from the wound towards the blood during the early days after the incident while maintaining the long term behaviour.

The fit has been not rejected by the IDEAS criterion as the p-value is 0.256. In this case the estimated deposited activity in the wound has the value of 1641 Bq. This value is a factor of 4 above the direct measurement evaluation of the deposited activity, (410 Bq) but is consistent with the value reported in reference [] at Table 3 for IMBA excretion model (1539 Bq). The data and the fitting are depicted in Figure 6.13.

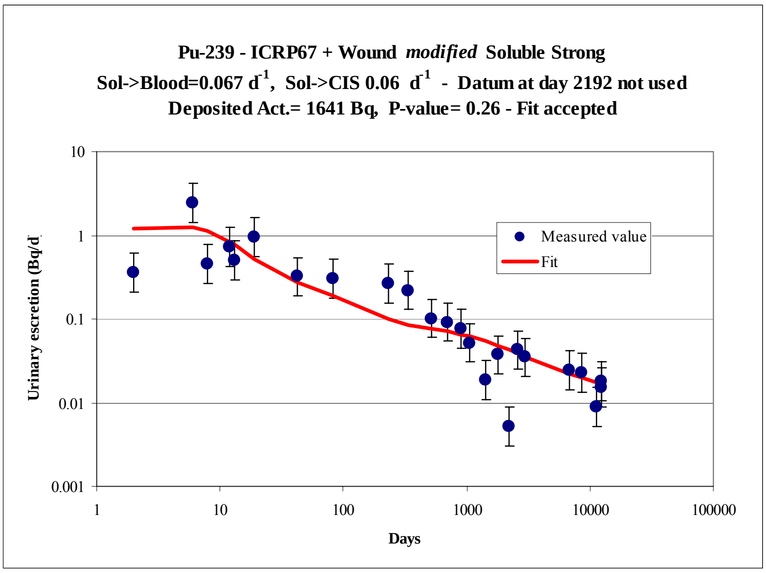

Figure 6.13: Case 235: Experimental data and fitting with Pu modified Soluble Strong wound model

So the suggestion derived from the evaluation of this case is that if it is not possible to fit the behaviour of the data after having already used different default NCRP model categories, as last trial, try to change a single wound clearance parameter value. The reduction of the overall output transfer parameter value from the compartment “soluble” by a factor of 10, permit to fit better the early data.

Case 236

This is a case of a 0.3 cm puncture laceration (caused by a knife, through the glove of a glove box) to the lateral aspect of the mid-proximal phalanx, left index finger. The incident occurred on 9 March 1967 and was reported as case 177 in the paper of Falk []. The estimation of the chemical form of Pu indicates relatively insoluble oxide form although more soluble compounds are possible. The first evaluation of the deposited amount after excision resulted in a value of 480 Bq which reduces to 150 ± 37 Bq, 32 years after the incident (June 1999).

Only seven urine data are available for this case from day 4 (value about 300 mBq/d) up to 32 years after the incident. The last values remain about 14-15 mBq/d. The rather constancy of the data and the possible presence of insoluble compounds suggest to apply a colloid model.

The fitting is accepted as the p-value is equal to 0.27. The estimated value of deposited material (1684 Bq) is a factor of 4 greater than the estimated initial value after excision. Also in this case the order of magnitude of the deposited material is consistent with that indicated for IMBA excretion model in Table 3 of reference [] for case 177 (1370 Bq).

Except for the first datum, the colloid behaviour seems to describe adequately the behaviour of the urine excretion. The values and the relative fitting are reported in Figure 6.14.

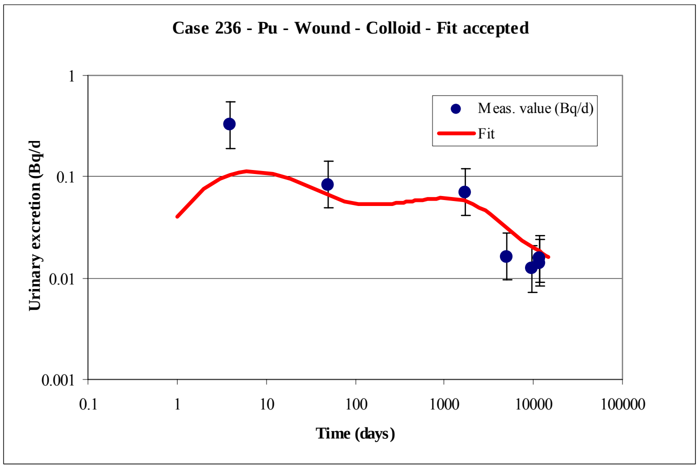

Figure 6.14: Case 236: Experimental data and fitting with Pu wound model colloid

Case 237

The case occurred on 9 February 1964. A 26-year-old Pu process operator sustained a puncture wound to a depth of nearly 1 cm to the right palm of hand, opposite the thumb, during a glove box bag out operation, when he grabbed a contaminated scale balance.This has been referred as case 626 in the Falk paper [].

The retained activity in February 1964, following the excision, has been estimated in 1600 Bq of Pu. A re-evaluation of the wound activity performed in May 2003 (i.e. more than 39 years after the incident) indicates a residual Pu activity of 3220 ± 600 Bq, notably higher than that estimated with the primitive wound counter in 1964.

The behaviour of the urinary excretion is practically constant and suggests to fit it by means of a Colloid model.

Sixty-three urine data are available from day 2 up to day 14336.

The fitting of the data is rejected by the IDEAS criteria also not considering the four data points at days 6, 163, 789 and 2017 which has been identified as rogue data (p-value = 9E-10).

In Figure 6.15 the experimental data and the tentative fitting are reported.

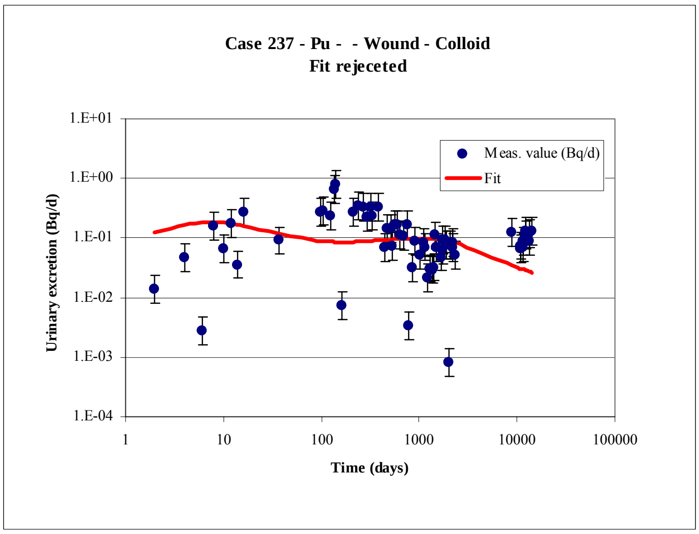

Figure 6.15: Case 237: Experimental data and fitting with Pu wound model Colloid

In such cases it is very difficult to fit the constant excretion behaviour indicated by experimental data. An attempt of fitting the overall clearance parameter values inside the colloid category is not successful to describe adequately the data.

Case 238

The case is also reported in the paper of Falk [] with reference case number 819. The incident occurred on 1st December 1967. A process operator was preparing to bag out a broken glass submersion heater and sustained a laceration, 1.5 cm in length, on the lateral part of the phalanx of his left thumb. An elliptical excision of the laceration and surrounding tissue was closed with one subcutaneous suture and six skin sutures. 520 Bq of plutonium remained following the excision. His last wound count on 11 October 1999 is equal to 270 ± 48 Bq.

Forty-two urine data are available from day 8 up to approximately 32 years after the incident. The values span from 3 to 150 mBq/d.

Also in this case the standard colloid model has been tried to fit the data without success (p-value= 1E-4). By chance the estimated deposited material is 794 Bq, which has the same order of magnitude of the estimated amount of Pu after excision. The standard NCRP colloid model is not able to correctly represent the behaviour of the urine data. In Figure 6.16 the experimental values of case 238 and the fitting, are displayed.

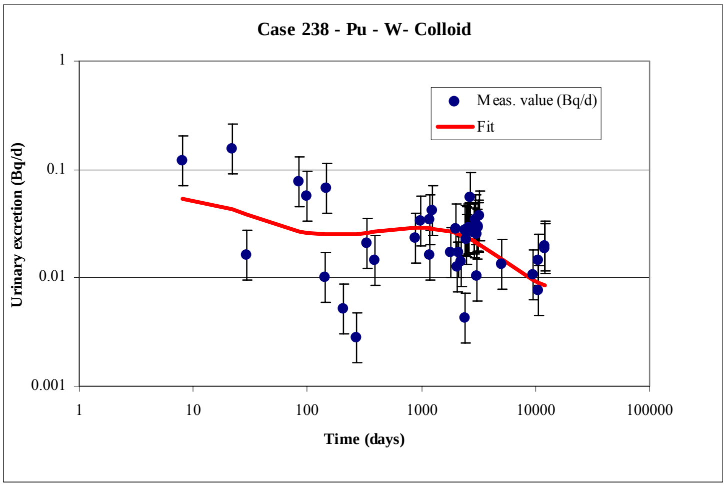

Figure 6.16: Case 238: Experimental data and fitting with Pu wound model Colloid

6.2.1 *Conclusions on the experience gained*

As general conclusion of the experience done with ^{239}Pu cases in which only the initial excision was performed (exception for case 234) and no chelation therapy was undertaken, the following conclusions can be drawn.

As indicated in the summary Table 6.2 of evaluations, in three cases the analysis for rogue data, as suggested in IDEAS Guidelines, has demonstrated their presence (cases 42, 235, 237).

The fit of the data has been accepted for the first 5 cases.

The soluble strong model has been accepted for the fitting of the data in all of the 3 cases that present decreasing behaviour of excretion data (cases 42, 61 and 235). In the case 235 the early excretion can be better fitted decreasing by a factor of 10 the overall output transfer rate from the “soluble” compartment. In this case the evaluated deposited activity in wound dose not fit the value evaluated by means of direct measurements (factor of 4 of overestimation).

The nearly constant excretion present in the remaining four cases has been tried to be fitted by a colloid behaviour. Only in two cases out of four the fit is accepted by the IDEAS goodness of fit requirement. In one case the estimated value of the deposited activity in wound has the same order of magnitude of that evaluated by means of direct measurements (case 234). For the other cases in which the fit has been accepted, the value of wound deposition does not fit with that evaluated by means of direct measurements. Some possible uncertainty connected to the direct wound measurement during the sixties, can also be supposed.

In the two cases (237 and 238) it is not possible to describe the behaviour of such observable by means of a single wound category model. Clustering of data due to time selection of the measurements and scattering of single values are other facts that do not permit the fit of the data.

Table 6.2: Summary table of the evaluations

Case number	Bioassay behaviour	Category of wound model used	Fit	Evaluated rogue data	Evaluated deposited material (Bq)	Notes
42	Decreasing	Soluble strong	Accepted	One	465	-
61	Decreasing	Soluble strong	Accepted	No	NE	-
234	Nearly constant	Colloid	Accepted	No	1907	The evaluated deposited material fits the wound direct measurement value.
235	Decreasing	Soluble Strong	Accepted	One	1641	Soluble strong with one modified parameter value, but the evaluated deposited material does not fit the direct measurement value.
236	Nearly constant	Colloid	Accepted	No	1684	The evaluated deposited material does not fit the direct measurement value.
237	Nearly constant	Colloid	Rejected	Four	-	Not possible to adequately describe the urine excretion data.
238	Nearly constant	Colloid	Rejected	No	-	Not possible to adequately describe the urine excretion data.

NE = Not evaluated, due to different element.

6.2.2 *Further work*

The discussion inside the group has covered problems related on how to deal with cases for which the general behaviour of the data is not in accordance with that indicated for the soluble categories (weak, moderate, strong and avid) or that for insoluble materials (as colloid, particles or fragment).

For the time being only a suggestion to try to fit the experimental data with a mixture of excretion function per unit deposited activity related to two different categories (e.g. inside the “Soluble” family or inside insoluble materials) can be presented.

Further work has to be done to answer the question related to the choice of which parameter value inside the different models can be changed when the model prediction does not fit the observed data. It would be good to perform a sensitivity analysis regarding the parameter value of the different wound model categories mostly affecting the observable quantity (e.g. the daily urinary excretion) and consider the physiological meaning of the variation of them.

6.3 Special procedure for wound cases.

In relationship to the suggestion to try to fit the experimental data by means of default or mixture of default model categories, the following flow charts to be introduced inside the structured approach of the IDEAS Guidelines are proposed. Stage 8A relates to the assignment of one default model category; stage 8B is related to the systematic trial of fitting using all the seven available default categories. Stage 8C is related to the tentative of mixing the experimental data by means of linear combinations of the predicted excretion functions per unit deposited activity calculated on the basis of two available category models connected to the same systemic model.

Inside the Figure 6.4 of the IDEAS Guidelines [] the step 4.4 will present also the check of wound pathway. In step 4.4.1 the wound pathway will send to Stage 8 that is subdivided into three stages. This is the description of stages 8A, 8B and 8C.

Stage 8A

In this stage, a simple evaluation is carried out using parameter values chosen *a priori*: before the evaluation (see Figure 6.17). The procedure is very similar to the “Standard procedure” (Stage 3). The main difference is that in a special procedure there should be more than one measurement.

Step 8.1: Identification and preparation of measurement data representing the case. It is expected that there will be more than one measurement available for a special assessment (M_i for i = 1 to n). It is therefore important that realistic uncertainties are assigned to the data (“scattering factor”, SF, Step 2.1). There may be more than one type of measurement (urine, faeces, etc), and there may be measurements of more than one radionuclide involved in the exposure. Usually for wound incident the time of intake is known.

Step 8.2: Assessment of contribution of previous intakes. The contributions (P_i) from all previous intakes of the radionuclide considered are calculated, taking into account all pathways of intake and all intakes of mixtures where the radionuclide was involved. The net values ($N_i = M_i – P_i$) of the radionuclide are calculated by subtracting P_i from the measured value M_i.

Step 8.3: Assign *a priori* parameters according to the suitable NCRP wound model category. A NCRP wound category should be assigned and the relative default parameter values should be assumed. Perform the choice of the NCRP category on the basis of the behaviour in time of the monitored quantity (e.g. daily urinary excretion). For Plutonium isotopes, choose “Soluble Strong” for decreasing behaviour; for nearly constant behaviour use “Colloid”. For daily urinary excretion increasing during time, use “Particles” or “Fragment” category.

Step 8.4: Calculate dose with a priori parameters. Using the assigned *a priori* parameter values, an estimate of wound deposited activity I_i is obtained by dividing the net value $N_i = M_i – P_i$ by the appropriate excretion function calculated by linking the NCRP wound model with the suitable systemic model. Use the equations presented in Step 5.5 from Stage 5Aof the IDEAS Guidelines. Using the same assigned *a priori* parameter values (both for wound and systemic models) the committed effective dose is calculated by multiplying the “best estimate” of the wound deposited activity by the appropriate dose coefficient (dose per unit wound activity). For ^{239}Pu the dose coefficient for intravenous injection may be applied to every NCRP category with a fairly conservative approximation, except for the category “Fragments”.

Step 8.5: If the committed effective dose estimated in Step 8.4 (from the intake under consideration and taking into account all available monitoring data) is less than 1 mSv, there is no need for further investigation (Step 8.5.1). Otherwise further special procedures (Stage 8B) are needed for more detailed evaluation of the case.

Step 8.5.1: The results in terms of wound deposited activity and committed effective dose from Step 8.4 are recorded together with the corresponding parameter values of the NCRP wound category (from Step 8.3).

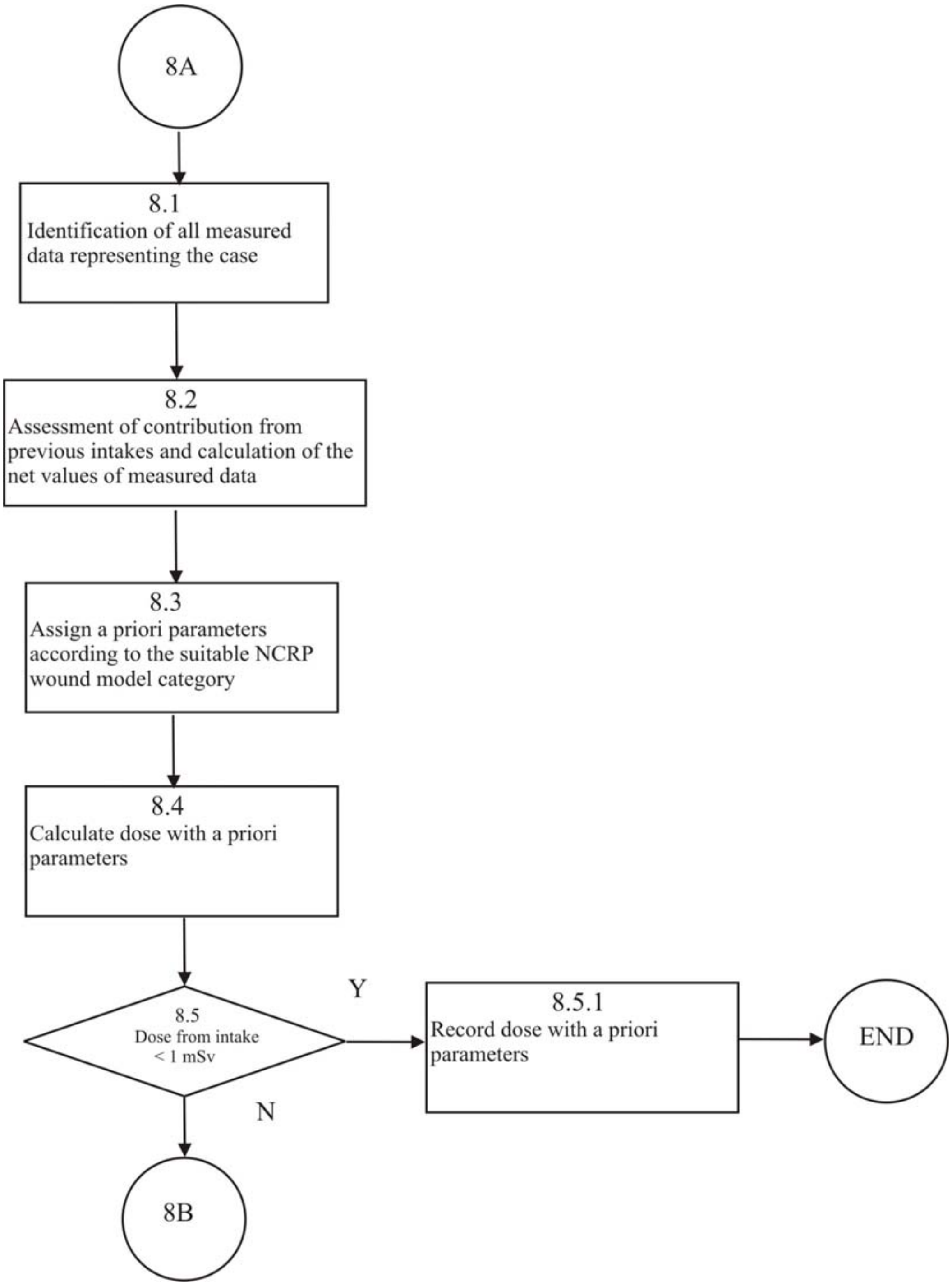
8A
8.1
Identification of all measured data representing the case
8.2
Assessment of contribution from previous intakes and calculation of the net values of measured data
8.3
Assign a priori parameters according to the suitable NCRP wound model category
8.4
Calculate dose with a priori parameters
8.5
Dose from intake < 1 mSv
Y
8.5.1
Record dose with a priori parameters
END
N
8B

Figure 6.17: Stage 8A. Special procedure for wound cases above Level 1 – Part 1: simple evaluation using parameter values chosen *a priori*.

Stage 8B

In this stage, a procedure is described for trying to fit the data considering at a turn different NCRP default categories and comparing the to the measured data. If an acceptable fit is not obtained with the assigned parameter values, a mix of default categories could be tried in Stage 8C. In Figure 6.18 the flow chart related to the stage is presented.

In this Stage 8B, and in Stage 8C that follows, NCRP wound categories are selected or mixed, and the dose assessment is evaluated on the basis of the “fit” of the model predictions to the observations (data). A check on whether the fit is adequate is used to decide whether to stop the evaluation, or to go on to further steps. A measure of the “Goodness of fit” and the criteria for deciding that the fit is good enough are therefore critical issues. It is important that there should be sufficient data available for assessment of a significant dose, and the higher the dose, the better the data should be. Proposals are therefore made for the minimum amounts of data that would be acceptable.

Step 8.6: Are there sufficient data? Criteria for the “sufficient” number (and types) of relevant data, duration of monitoring etc., are proposed according to the dose (see Table 4.1 in the IDEAS Guidelines document or Tables 7.1 and 7.2 in this document). In this step, the numbers for the range 1 mSv < Dose < 6 mSv are appropriate.

Step 8.7: Get additional dose relevant data. This assumes that the evaluation is being carried out in real time, so that the opportunity exists to obtain more measurements if those available are insufficient. (For historical cases, where it is not possible to obtain more measurements, it should be recorded that the data are insufficient, and therefore the result should be treated with caution.) When the additional data have been obtained, a simple re-evaluation from Stage 8A is made.

Step 8.8: Assume NCRP “Soluble Weak” category. This is the first step for the systematic evaluation of the different default categories as indicated by NCRP. In this step the values of the measured quantity (e.g. daily urinary excretion) per unit deposited activity in wound, for the default NCRP category linked with the suitable systemic model, must be calculated.

Step 8.9: Calculate dose with NCRP default category parameter. By means of the values calculated in Step 8.8 an estimate of the deposited activity in wound is performed also using the equations presented in Step 5.5 from Stage 5A of the IDEAS Guidelines. The committed effective dose is evaluated via the dose coefficient. (see also note on ^{239}Pu on Step 8.4).

Step 8.10: Is the goodness of fit acceptable? If the goodness of fit is acceptable (i.e. the fit obtained is not rejected by the specified criteria) go to Step 8.11 for the check of the dose. The estimated deposited activity is taken as the best estimate. Otherwise go to Step 8.12 to begin the iterative process to try other different NCRP wound categories.

Step 8.11: Is the dose less than 6 mSv? If the effective dose estimated in Step 8.9 is less than 6 mSv, there is no need for further investigation (Step 8.11.1). Otherwise further special procedures are needed (Stage 8C).

Step 8.11.1: Record dose with all parameters. The results in terms of wound deposited activity and committed effective dose from Step 8.9 are recorded together with the corresponding parameter values.

Step 8.12: Try another NCRP default category. Iteratively set the NCRP wound model to “Soluble Moderate”, “Soluble Strong”, “Soluble Avid”, “Colloid”, “Particle” and “Fragment”. Use the default parameter values.

Step 8.13: Already tried all NCRP default categories? If no, go back to Step 8.9 to calculate dose with a new default category. Otherwise, when all the 7 categories have been already evaluated, go to Stage 8C.

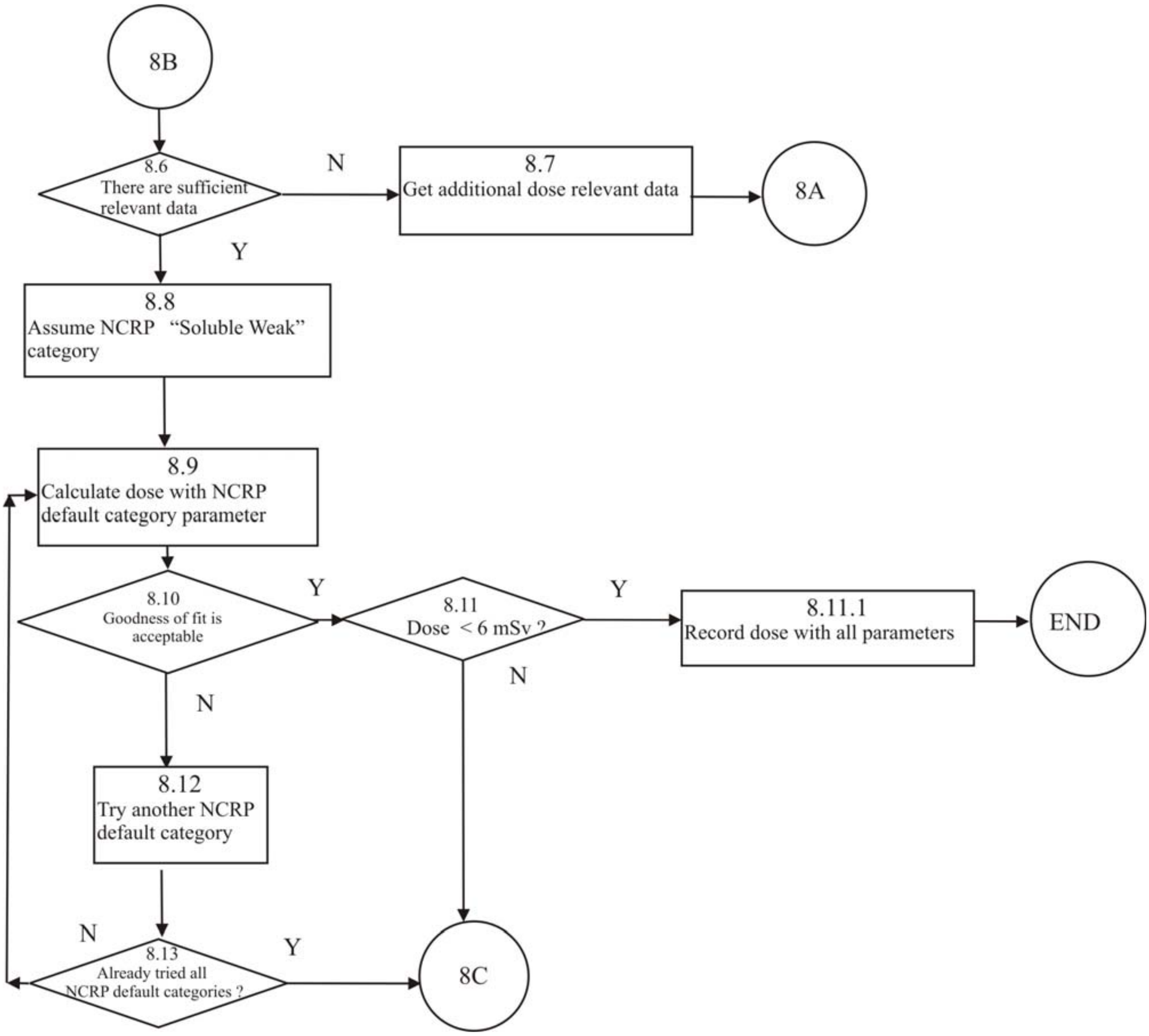
8B
8.6
There are sufficient relevant data
N
Y
8.7
Get additional dose relevant data
8A
8.8
Assume NCRP “Soluble Weak” category
8.9
Calculate dose with NCRP default category parameter
8.10
Goodness of fit is acceptable
Y
8.11
Dose < 6 mSv ?
Y
8.11.1
Record dose with all parameters
END
N
N
8.12
Try another NCRP default category
N
8.13
Already tried all NCRP default categories ?
Y
8C

Figure 6.18: Stage 8B: Special procedure for wound cases above Level 1: Part 2 Evaluation by means of different NCRP default categories.

Stage 8C

The stage 8C may have been reached through Step 8.11 for an accepted fit with committed effective dose greater than 6 mSv or after having tried all the 7 default categories for the NCRP wound model. In this stage the bioassay calculated values per unit deposited activity are calculated by linearly combining the different bioassay values related to the different NCRP wound categories using the same systemic model.

Step 8.14: Check the number of data required for evaluation at this level and get more data, if necessary. This is similar to Step 8.7. Criteria for the “sufficient” number (and types) of relevant data, duration of monitoring etc., are proposed according to the dose level. In this step, the numbers for Dose > 6 mSv are appropriate.

To get additional dose relevant data assumes that the evaluation is being carried out in real time, so that the opportunity exists to obtain more measurements if those available are insufficient. (For historical cases, where it is not possible to obtain more measurements, it should be recorded that the data are insufficient, and therefore the result should be treated with caution.) When the additional data have been obtained, further special procedures (Step 8.15 onwards) are needed for more detailed evaluation of the case.

Step 8.15: Assessment of dose by fitting a mixture of two “Soluble” categories. This is an extension of Step 8.9, to give greater flexibility in fitting by considering a mixture of NCRP soluble categories. This step may have been reached through Step 8.13, because an acceptable fit was not obtained with any NCRP default category. In that case combinations of NCRP categories should be tried by inspection, trial and error etc. Use at a turn a mixture of “Soluble” categories: “Weak + Moderate”, “Moderate + Strong”, “Strong + Avid”. If more than one mixture of NCRP categories fits the data, the mixture which gives the best fit is chosen.

Alternatively, this step may have been reached through Step 8.11 because the estimated dose is > 6 mSv. In that case begin the evaluation using the NCRP category which provides the good fit in Step 8.10 and increase the relative fraction of another category, beginning with no contribution.

Step 8.16: Is the Goodness of fit acceptable? If the goodness of fit related to a certain mixture of categories is acceptable (i.e. the fit obtained is not rejected by the specified criteria) go to Step 8.16.1 for the record of the dose with all parameters. Otherwise go to Step 8.17. If more fitting are accepted by the indicated criteria use as best estimate that which provides the highest p-value based on $\square_0^2$.

Step 8.16.1: Record dose with all parameters. The results in terms of wound deposited activity and committed effective dose from Step 8.15 are recorded together with the corresponding parameter values.

Step 8.17: Assessment of dose by fitting a mixture of other NCRP categories as indicated. This is an extension of Step 8.15, to give greater flexibility in fitting by considering a mixture of NCRP insoluble categories. Use at a turn a mixture of these categories: “Soluble strong + Colloid”, “Colloid + Particle”, “Particle + Fragment”. If more than one mixture of NCRP categories fits the data, the mixture which gives the best fit is chosen.

Step 8.18: Is the Goodness of fit acceptable? If the goodness of fit related to a certain mixture of categories is acceptable (i.e. the fit obtained is not rejected by the specified criteria) go to Step 8.18.1 for the record of the dose with all parameters. Otherwise go to Step 8.19.

Step 8.18.1: Record dose with all parameters. The results in terms of wound deposited activity and committed effective dose from Step 8.15 are recorded together with the corresponding parameter values.

Step 8.19: Consult other experts. If it is not possible to fit the data, also by means of mixtures of NCRP default categories, consult other experts.

The flow chart of Stage 8C is reported in Figure 6.19.

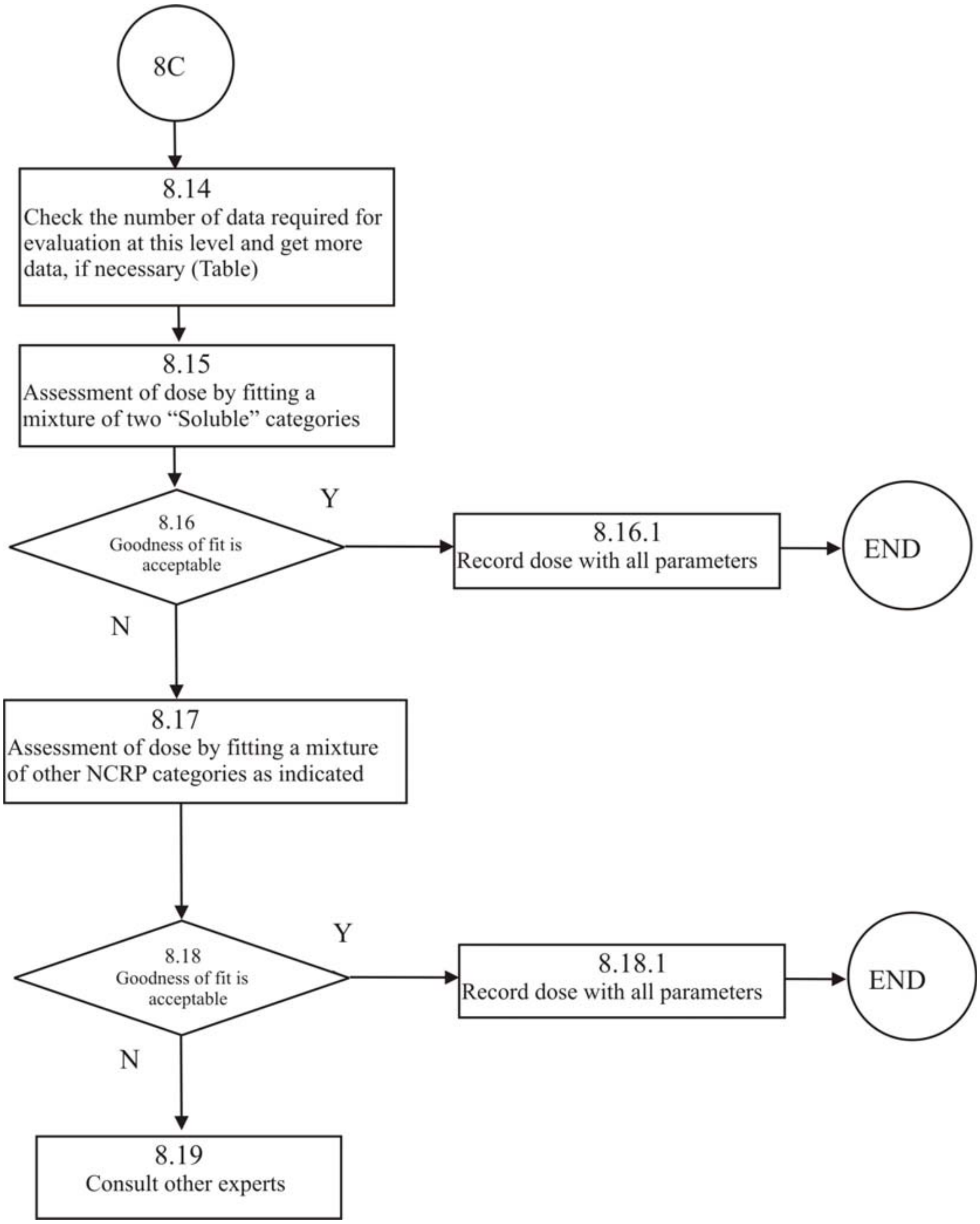
8C
8.14
Check the number of data required for evaluation at this level and get more data, if necessary (Table)
8.15
Assessment of dose by fitting a mixture of two "Soluble" categories
8.16
Goodness of fit is acceptable
Y
N
8.16.1
Record dose with all parameters
END
8.17
Assessment of dose by fitting a mixture of other NCRP categories as indicated
8.18
Goodness of fit is acceptable
Y
N
8.18.1
Record dose with all parameters
END
8.19
Consult other experts

Figure 6.19: Stage 8C: special procedure for wound cases above Level 1 – Part 3: Evaluation performed by means of mixture of default NCRP categories.

7 ASPECTS OF DATA HANDLING

7.1 Number and type of data required for assessment of dose

The IDEAS Guidelines suggested the minimum number and type of monitoring data required for dose assessment for some selected radionuclides. The greater the dose range the greater the number of data is required.

This work has been extended for different categories of radionuclides (Table 7.1). It should be point out that Table 7.1 is presented to illustrate the point that more measurements should be taken the greater the dose estimate. It should not be seen as being too prescriptive and is open for discussion.

Table 7.1 Minimum number and type of data required for assessment of dose for some categories of radionuclides.

Category of radionuclide	Type of monitoring	Number of required monitoring data		
		D < 1 mSv (minimum requirement)	1 mSv < D < 6 mSv^a	D > 6 mSv^b
All type of α-emitters with significant γ-component (U-235, Am-241 etc.)	Urine	-	2	3
	Faeces	1	2	3
	Whole body, critical organ or wound site, respectively.	-	2	4
All type of α-emitters without significant γ-component (Po-210, Pu-239 etc.)	Urine	-	3	5
	Faeces	1	3	5
All type of β-emitters with significant γ-component (Co-60, I-131, Cs-137 etc.)	Whole body, critical organ or wound site, respectively.	1	2	4
	Urine	-	2	4
F-type β-emitters without significant γ-component (H-3, C-14 etc.)	Urine	1	4	8
M/S-type β-emitters without significant γ-component (Sr-90 etc.)	Urine	1	2	4
	Faeces	-	2	4
Pure γ-emitters (I-123 etc.)	Whole body or critical organ	1	2	4
	Urine	-	2	4

a) The monitoring data should cover a time range of 30 d; if the effective half-life is less than 30 d, the monitoring data should cover a time range corresponding to the effective half-life.

b) The monitoring data should cover a time range of 60 d; if the effective half-life is less than 30 d, the monitoring data should cover a time range corresponding to twice the effective half-life.

Based upon the information given in Table 7.1, the minimum number and type of monitoring data required for dose assessment for some selected radionuclides are given in Table 7.2.

The values given in Table 7.1 are based on judgment and experience. One way to obtain a quantitative approach in deciding the number of data required, is to carry out uncertainty studies. Such studies can be used to determine the minimum number of measurements required to estimate an intake and dose with a given uncertainty (Section 3.7).

Table 7.2 Minimum number and type of data required for assessment of dose for some selected radionuclides and the respective monitoring procedures

Radionuclide	Type of monitoring	Required monitoring data					
		D < 1 mSv		1 mSv < D < 6 mSv		D > 6 mSv	
		Number	Time range (days)	Number	Time range (days)	Number	Time range (days)
H-3	Urine	1	-	4	10	8	20
Co-60	Whole body	1	-	2	30	4	60
	Urine	-	-	2	30	4	60
Sr-90	Urine	1	-	2	10	4	20
	Faeces	-	-	2	10	4	20
I-131	Thyroid	1	-	2	7	4	14
	Urine	-	-	2	7	4	14
Cs-137	Whole body	1	-	2	30	4	60
	Urine	-	-	2	30	4	60
U-235	Urine	-	-	2	30	3	60
	Faeces	1	-	2	30	3	60
	Lungs	-	-	2	30	4	60
Pu-239	Urine	-	-	3	30	5	60
	Faeces	1	-	3	30	5	60
Am-241	Urine	-	-	2	30	3	60
	Faeces	1	-	2	30	3	60
	Lungs	-	-	2	30	4	60
	Skeleton[a]	-	-	1	-	2	60

[a] These measurements are desirable if facilities are available.

7.2 Lower limit of detection (LLD) values

Table 7.3 gives LLD values for direct (*in vivo*), indirect (*in vitro*) and room air monitoring measurements. These values were suggested by German experts, reviewing up to date methodologies [32]. At the end of the table some values for measurements in liver and skeleton for selected radionuclides are also reported.

Table 7.3 LLD values for different in vivo and in vitro determinations

Radionuclide	LLD (in vivo) [Bq]			LLD (in vitro) [Bq/d]		LLD [Bq/m^3]
	Whole - body	Thyroid	Lungs	Urine	Feces	Room air
H-3				100		100
Be-7	300					
C-11						100
C-14				40		10
F-18						100
Na-22	50					
Na-24	30					100
Mg-28	50					100
P-32				20		
P-33				20		
S-35				20		
Cl-36				20		
K-42	200					100
Ca-45				20		
Sc-46	50					
Cr-51	500					
Mn-54	50					
Fe-55					20	
Fe-59	75			0.1		
Co-57	100			1		
Co-58	50			1		
Co-60	50			1		
Ni-59				20		
Ni-63				20		
Cu-64	200					100
Zn-65	180					
Ga-67	200					
Se-75	100					
Sr-85	75			1		
Sr-89				0.05		
Sr-90				0.05		
Y-88	50					
Y-90				1	1	10
Zr-95	75					
Nb-94	100					
Nb-95	50					
Mo-99	50			1		
Tc-99m	100					100
Tc-99				5		
Ru-103	50					
Ru-106	200			5		
Rh-105	100					10
Ag-108m	100					
Ag-110m	50					
Cd-109				20		
In-111	50					
In-113m	100					100
Sn-113	75					
Sb-122	50					10
Sb-124	75					
Sb-125	150					
Te-123m	50					

Radionuclide	Whole - body	Thyroid	Lungs	Urine	Feces	Room air
Te-132	50					
I-123		25				10
I-124						1
I-125		50		1		
I-129		50		1		
I-131		25		1		
I-132		25				100
I-133		25				100
Cs-134	50			1		
Cs-137	50			1		
Ba-133	100					
Ba-140	150					
La-140	50					10
Ce-141	150					
Ce-144	500					
Pr-144						100
Pm-147				20	20	
Eu-152	150					
Eu-154	150					
Eu-155	250					
Yb-169	150					
Hf-181	50					
Ta-182	150					
Re-186				20		10
Ir-192	75					
Hg-197	250					
Hg-203	75					
Tl-201	500					
Tl-204	5000					
Pb-210				0.1	5E-4	
Po-210				0.001		
Ra-224				0.001		
Ra-226	200			0.001		
Ra-228	200			1		
Th-228			10	0.001	0.001	0.01
Th-230			100	0.001	0.001	0.01
Th-232			10	0.001	0.001	0.01
U-233			100	0.001	0.001	0.01
U-234			100	0.001	0.001	0.01
U-235			3	0.001	0.001	0.01
U-238			50	0.001	0.001	0.01
Np-237			10	0.001	0.001	0.01
Np-239	500		10	0.001	0.001	0.1
Pu-238			700	0.001	0.001	0.01
Pu-239			2100	0.001	0.001	0.01
Pu-240			1000	0.001	0.001	0.01
Pu-241				0.015	0.015	0.1
Pu-242			1000	0.001	0.001	0.01
Am-241			5	0.001	0.001	0.01
Am-243			100	0.001	0.001	0.01
Cm-242			1000	0.001	0.001	0.01
Cm-243			1000	0.001	0.001	0.01
Cm-244			1000	0.001	0.001	0.01
Cm-246			1000	0.001	0.001	0.01
Cm-248			1000	0.001	0.001	0.01

In addition:
Pb-210 in the skeleton 100 Bq
Am-241 in the liver 8 Bq
Am-241 in the skeleton 25 Bq

8 IDEAS DATABASES

During the IDEAS project(2), three databases: the “Bibliographic Database” , the “Internal Contamination Database” and the Evaluation Database” have been developed(3, 33).

The “Bibliographic Database” is a compilation of publications from the literature, which contained information on cases of internal contamination from which intake and committed doses could be assessed. At this stage papers were included which might (but were not certain to) contain such information, or which included references to papers which contained such information. By the end of this period, a comprehensive “Bibliographic Database” containing about 585 references has been compiled. During the CONRAD project, new references have been added to the database, some references have been corrected or completed and repeated references have been removed.

The “Internal Contamination Database” contains cases of internal contamination compiled from references of the previous database. The database consists of the case description and of the monitoring results. The Internal Contamination Database now contains 255 cases. Some 50 cases have been added during the CONRAD Project. All these cases cover about 42 radionuclides of 30 elements (Table 8.1)

The great majority of intakes concerned inhalation cases, but other intake route are also found (ingestion, wound, injection, skin contamination) (Table 8.2). All the different monitoring types are observed in the database. In decreasing number of occurrence these are: urine, faeces, whole-body, lungs, organ, thyroid, air monitoring, wound, PAS, nose-swab, breath and nose-blow. All the cases in the database are not equivalent. Some of them contained more than 150 monitoring results and some contained as few as only 2 results. During the CONRAD project, new cases have been added to the database and these data have been used by several Task Groups. The database contains 50 cases where DTPA therapy has been used. Some of these cases have been used by the DTPA Task Group.

Data contained in this IDEAS Internal Contamination Database have been used to evaluated mathematically the scattering factor (SF) values for different radionuclides and type of monitoring data. (Section 2). Seven of the 29 wound cases have been used for the application of the NCRP wound model. These cases were not influenced by DTPA therapy (Section 6).

Also available is the Evaluation Database. In WP3 of the IDEAS project, evaluations provided by the contractors were collated in an Evaluation of Cases Database. This database contains a summary of information for 95 evaluations on 52 cases (17 radioisotopes) permitting the comparison of different approaches to evaluation on the same case scenario, and providing links to the IDEAS Internal Contamination Database, where the original monitoring data can be found. From the database it is also possible to open the file describing each evaluation where detailed information on each contractor’s approach, assumed hypotheses and parameters can be found.
The selection of cases to be evaluated was made on the basis of the radioisotope or mixture present in the case scenario, complexity present in the data set (e.g. multiple types of monitoring data) and special issues to be considered in the IDEAS guidelines.

All these databases are available for download at http://www.sckcen.be/ideas/ . It should be noted that, **if you have contamination cases which are not in the Internal Contamination Database, we are interested in these cases.**

Table 8.1 Main contaminant observed in the Internal Contamination Database

Main Contaminant	Number of occurrence	Main Contaminant	Number of occurrence
^{110m}Ag ^{58}Co ^{60}Co ^{54}Mn ^{124}Sb	1	^{203}Pb	11
^{241}Am	18	^{210}Po	1
^{133}Ba	1	Pu	25
^{207}Bi	2	Pu - Am	9
^{45}Ca	1	$^{238/239}$Pu	2
^{47}Ca ^{85}Sr	1	$^{238/239}$Pu ^{241}Am	3
^{144}Ce	1	^{239}Pu	22
^{244}Cm	6	^{239}Pu ^{241}Am	1
^{58}Co / ^{57}Co	1	^{226}Ra	5
^{60}Co	25	^{103}Ru	1
^{60}Co / ^{144}Ce / ^{137}Cs	1	^{35}S	1
^{60}Co / ^{57}Co / ^{65}Zn / ^{131}I	2	^{85}Sr	1
^{60}Co / ^{65}Zn	2	^{90}Sr	10
^{137}Cs	6	^{90}Sr / ^{90}Y	3
^{137}Cs $^{141/144}$Ce $^{103/106}$Ru ^{95}Zr ^{95}Nb	1	^{90}Sr ^{103}Ru ^{137}Cs	1
^{137}Cs ^{60}Co	1	Th	1
^{137}Cs ^{90}Sr	2	^{202}Tl	1
^{3}H	9	^{170}Tm	1
^{203}Hg	5	U	34
^{125}I	13	^{234}U ^{235}U ^{238}U	1
^{131}I	1	^{234}U ^{238}U ^{230}Th	2
^{131}I ^{134}Cs ^{137}Cs ^{58}Co ^{60}Co	1	^{235}U	6
^{192}Ir	1	^{65}Zn	1
^{54}Mn	1	^{65}Zn ^{110m}Ag	1
^{32}P	2	^{95}Zr	4
^{231}Pa	1	^{95}Zr ^{95}Nb	1

Table 8.2 Type of intake observed in the Internal Contamination database.

Type of Intake	Number of occurrence
Chronic Intake	17
Ingestion	23
Inhalation	167
Injection	6

Type of Intake	Number of occurrence
Skin contamination	3
Unknown	10
Wound	29

9 CONCLUSIONS

The work carried out in Task Groups 5.1 and 5.5 includes evaluation of SF values, uncertainty studies, revision of IDEAS guidelines and update of IDEAS databases.

It was very important to draw on the group members' expertise especially in the revision of the guidelines. The IDEAS Guidelines have been revised in areas relating to the evaluation of an effective AMAD, guidance on evaluating wound cases with the NCRP wound model and in aspects of data handling where the number and type of measurements required for dose assessment are suggested. More work is still required in giving guidance on evaluating wound cases. In particular, further advice is required on how to apply the NCRP wound model to real cases, especially for those cases when the model predictions do not fit the data with a default wound retention category.

Discussions among members of the group were useful in understanding the concepts of classical statistics and Bayesian statistics applied to retrospective dosimetry. Uncertainty studies were performed to investigated different intake pattern assumptions for routine monitoring. The Bayesian approach can be used to estimate the conditional probability of the intake or dose given the measurement data for special monitoring programmes. Such studies can be used to determine the minimum number of measurements required to estimate an intake and dose with a given uncertainty.

The IDEAS Databases have been updated, in particular, additional cases have been added to the IDEAS Internal Contamination Database, so that it now contains 255 cases.

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3.2.- CONRAD Task 5.2: Research Studies on Biokinetic Models

3.2.1.- CONRAD Task 5.2.1: Development, Implementation and Quality Assurance of Biokinetic Models

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CONRAD Task 5.2: Research Studies on Biokinetic Models

ABSTRACT

New biokinetic models have been implemented by several European institutions. Quality assurance procedures included intercomparison of the results as well as quality assurance of model formulation. Additionally the use of the models was examined leading to proposals of tuning parameters. Stable isotope studies were evaluated with respect to their implications to the new models and new biokinetic models were proposed on the basis of their results. Furthermore, the development of a biokinetic model describing the effects of decorporation of actinides by DTPA treatment was initiated (see another report within this volume).

3.2.1.- CONRAD Task 5.2.1: Development, Implementation and Quality Assurance of Biokinetic Models

CONTENTS

1	Introduction	97
2	HATM	98
	2.1 Results of calculations	100
	2.2 QA of model formulation	103
3	Wound model	105
	3.1 Results of calculations	105
	3.2 Comparison of results with approximation functions	108
4	Systemic models	110
	4.1 Results of polonium calculations	110
	4.2 Results of three plutonium model calculations	111
	4.3 Skeleton/liver partitioning factor	112
5	Stable isotope studies	115
	5.1 Results of absorption to the HAT	115
	5.2 Blood clearance and urinary excretion	115
	5.3 Proposal of new models	116
6	Conclusions	119

1 INTRODUCTION

Fifteen scientists from seven European countries have been working in the Task Group 5.2 "Research Studies on Biokinetic Models" within the Workpackage 5 "Internal Dosimetry" of the CONRAD project with the aim to coordinate research studies on biokinetic models and to evaluate the implications of new biokinetic models on dose assessment and safety standards.

Because CONRAD is dealing with occupational radiation protection only biokinetic models for workers were considered. Another reason for this is that ICRP is currently revising its biokinetic and dosimetric models for workers which have been evaluated by the CONRAD T5.2 group as far as they are already available.

To meet this aim several new biokinetic models (the ICRP Human Alimentary Tract Model (HATM) [1], the NCRP wound model [2] and systemic models) were implemented and the computational results were quality assured by intercomparison procedures. The work also included the evaluation of stable isotope studies and the development of a biokinetic model for the mechanisms of decorporation of actinides by diethylenetriaminepentaacetic acid (DTPA) for which a separate report is given in this volume.

2 HATM

ICRP has published a new age- and sex-dependent Human Alimentary Tract Model (HATM) in its publication 100 [1]. Compared to the old gastrointestinal model of ICRP Publication 30 [3] the most significant changes in biokinetics are the addition of the initial compartments of oral cavity and oesophagus with mean retention times of only several seconds and the possibility of absorption not only directly from the small intestine but from nearly all sites of the tract with potential retention in the walls and subsequent recycling into the contents of the tract. The biokinetic model (see Fig. 1) was implemented into computational codes by six different groups in five European countries: into the codes (a) of the Federal Office for Radiation Protection (BfS), Germany, and (b) of the Ukrainian Radiation Protection Institute Kiev which both were also used in ICRP quality assurance procedures as well as (c) into the IMBA code of the British Health Protection Agency, Radiation Protection Division, and into codes of (d) IRSN (France), (e) University of Milan and Helmholtz Zentrum München, National Research Center for Environmental Health (Italy/Germany) and (f) ENEA Bologna (Italy).

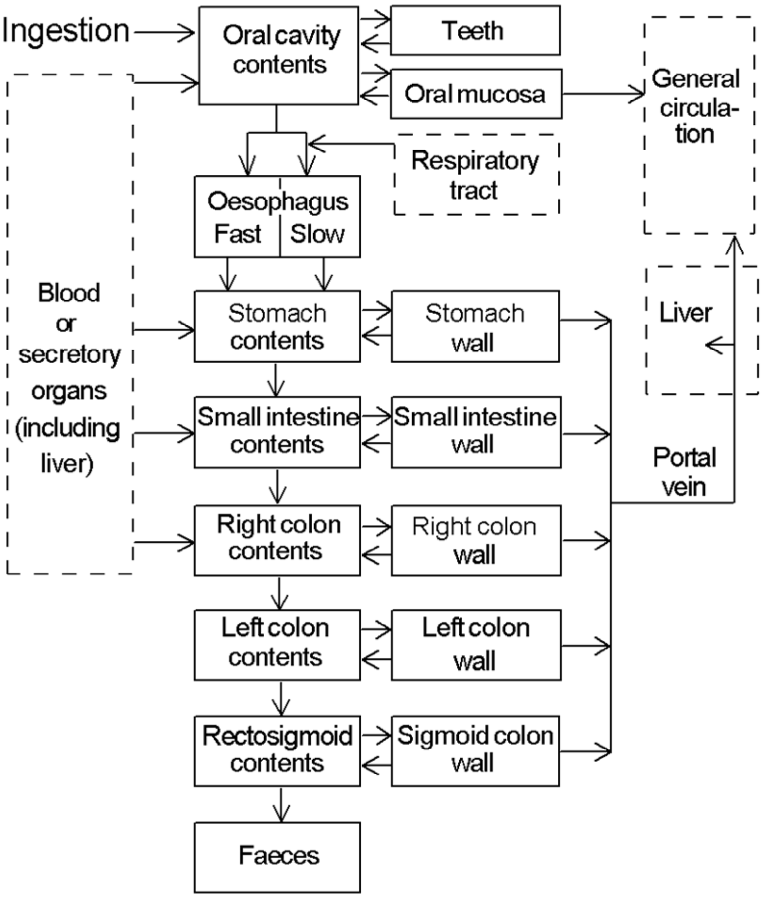

Fig. 1: Structure of the ICRP HATM [1]

Table 1: Numbers of disintegrations in the HATM and excretion rates

radionuclide	**^{133}Te**	**^{18}F**	**^{99m}Tc**	**^{127}Te**	**^{123}I**	**^{111}In**	**^{201}Tl**	**^{141}Ce**	**^{60}Co**	**^{129}I**	**^{238}U**
half-life	12.45 min	109.8 min	6.02 h	9.35 h	13.2 h	2.83 d	3.044 d	32.501 d	5.271 y	$1.57 \cdot 10^7$ y	$4.468 \cdot 10^9$ y
f_A	0.3	0.99	0.5	0.3	0.99	0.02	0.99	0.0005	0.1	0.99	0.02
organ	**number of nuclear transformations over 50 years**										
mouth	1.19E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01
oesophagus fast	6.19E+00	6.29E+00	6.30E+00	6.30E+00	6.30E+00	6.30E+00	6.30E+00	6.30E+00	6.30E+00	6.30E+00	6.30E+00
oesophagus slow	3.81E+00	3.98E+00	3.99E+00	4.00E+00	4.00E+00	4.00E+00	4.00E+00	4.00E+00	4.00E+00	4.00E+00	4.00E+00
stomach	8.40E+02	2.91E+03	3.70E+03	3.86E+03	3.96E+03	4.15E+03	4.15E+03	4.20E+03	4.20E+03	4.20E+03	4.20E+03
small intestine	1.95E+02	9.82E+01	5.15E+03	7.68E+03	1.35E+02	1.34E+04	1.42E+02	1.43E+04	1.30E+04	1.44E+02	1.41E+04
right colon	1.42E+01	5.31E+01	6.49E+03	1.22E+04	2.49E+02	3.58E+04	3.84E+02	4.25E+04	3.89E+04	4.32E+02	4.23E+04
left colon	3.46E-01	9.58E+00	2.73E+03	6.45E+03	1.53E+02	3.19E+04	3.44E+02	4.21E+04	3.88E+04	4.32E+02	4.23E+04
rectosigmoid col.	8.43E-03	1.73E+00	1.15E+03	3.42E+03	9.37E+01	2.84E+04	3.09E+02	4.16E+04	3.88E+04	4.32E+02	4.23E+04
time (d)	**daily excreted fraction of ingested activity in faeces**										
1		3.34E-07	8.00E-03	2.80E-02	8.40E-04	1.66E-01	2.36E-03	2.11E-01	2.00E-01	2.96E-03	2.12E-01
2			9.27E-04	9.37E-03	3.62E-04	2.84E-01	2.85E-03	4.52E-01	4.24E-01	4.50E-03	4.63E-01
3			2.58E-05	7.18E-04	4.26E-05	1.06E-01	9.42E-04	2.12E-01	1.99E-01	1.87E-03	2.21E-01
4			4.62E-07	3.49E-05	3.35E-06	2.44E-02	2.08E-04	6.12E-02	5.83E-02	5.18E-04	6.50E-02
5				1.38E-06	2.18E-07	4.53E-03	3.80E-05	1.42E-02	1.38E-02	1.19E-04	1.54E-02
6				4.84E-08	1.27E-08	7.44E-04	6.22E-06	2.92E-03	2.88E-03	2.44E-05	3.23E-03
7						1.13E-04	9.47E-07	5.55E-04	5.56E-04	4.66E-06	6.27E-04
8						1.62E-05	1.37E-07	9.96E-05	1.02E-04	8.46E-07	1.15E-04
9						2.24E-06	1.91E-08	1.72E-05	1.79E-05	1.48E-07	2.03E-05
10						2.99E-07		2.88E-06	3.06E-06	2.51E-08	3.46E-06

2.1 Results of calculations

Firstly, numbers of transformations in the various compartments and the daily faecal excretion rates according to the old gastrointestinal (GI) tract model and to the new HATM were calculated for eleven radionuclides with different half-lives ranging from 12.45 minutes (^{133}Te) up to $4.468 \cdot 10^9$ years (^{238}U) and different values of fractions of ingested activity which are absorbed to blood, f_A, ranging from 0.0005 to 0.99 with the assumption that – as it is in the old GI tract model – absorption is only from the small intestine without any retention in the wall (i.e. $f_A = f_1$). The results using the new model with the parameters for adult males are given in Table 1. Only excretion rates $>10^{-8}$ are given in this Table, therefore for ^{133}Te no excretion rates are given due to its very short half-life. Table 2 shows the comparison of model results between the old GI tract model and the new HATM for 3 radionuclides.

Table 2: Comparison of numbers of disintegrations in the compartments of the old ICRP gastrointestinal tract model [3] and the ICRP HATM [5] following intake of 1 Bq

radionuclide half-life f_A or f_1	^{133}Te 12.45 min 0.3		^{201}Tl 3.044 d 0.99		^{238}U $4.468 \cdot 10^9$ y 0.02	
	number of nuclear transformations over 50 years					
compartment	old	new	old	new	old	new
mouth	NA	1.2E+01	NA	1.2E+01	NA	1.2E+01
oesophagus	NA	1.0E+01	NA	1.0E+01	NA	1.0E+01
stomach	8.3E+02	8.4E+02	3.6E+03	4.2E+03	3.6E+03	4.2E+03
small intestine	2.2E+02	1.9E+02	1.4E+02	1.4E+02	1.4E+04	1.4E+04
right colon	NA	1.4E+01	NA	3.8E+02	NA	4.2E+04
upper large intestine	1.6E+01	NA	4.2E+02	NA	4.7E+04	NA
left colon	NA	3.5E-01	NA	3.4E+02	NA	4.2E+04
lower large intestine	3.6E-01	NA	6.2E+02	NA	8.5E+04	NA
rectosigmoid colon	NA	8.4E-03	NA	3.1E+02	NA	4.2E+04
large intestine/colon	1.7E+01	1.5E+01	1.0E+03	1.0E+03	1.3E+05	1.3E+05

NA	not applicable.
old	ICRP gastro-intestinal tract model [3].
new	ICRP HATM [5].

The comparison of the computational results showed excellent agreement: The discrepancies in the results of numbers of disintegrations calculated by different codes were less than 1%. The discrepancies in the results of the daily excretion rates were a little larger than those of the numbers of disintegrations but at the end also did not exceed 1%.

It could also be seen that the application of analytical and numerical, e.g. Runge–Kutta, methods both used by the BfS code DOSAGE showed almost no discrepancies. Only for the very short-lived radionuclide ^{133}Te these were up to 0.2% in the last compartments of the tract. This demonstrates that in spite of the very short transit times of a few seconds in the mouth and oesophagus analytical methods can also be applied for the computations.

As a next step also calculations for some (short) decay chains have been performed, for ^{90}Sr (f_A=0.3) with daughter ^{90}Y (f_A=10^{-4}) and for ^{234}Pu (f_A=$5\cdot10^{-4}$) with daughters ^{234}Np (f_A=$5\cdot10^{-4}$), ^{230}U (f_A=0.02) and ^{226}Th (f_A=$5\cdot10^{-4}$). The computed numbers of transformations with the assumptions of shared and independent f_A values within the decay chains are given in Table 3.

Table 3: Numbers of disintegrations of two decay chains in the HATM following intake of 1 Bq

f_A independent

Compartment	^{90}Sr	^{90}Y	^{234}Pu	^{234}Np	^{230}U	^{226}Th
Oral Content	1.20E+01	4.33E-04	1.20E+01	2.47E-04	3.33E-06	1.49E-08
Oesophagus fast	6.30E+00	3.60E-04	6.30E+00	2.05E-04	2.77E-06	1.50E-08
Oesophagus slow	4.00E+00	6.26E-04	4.00E+00	3.56E-04	4.81E-06	7.57E-08
Stomach Content	4.20E+03	5.27E+01	3.85E+03	2.76E+01	3.75E-01	2.29E-01
SI Content	1.01E+04	5.92E+02	1.00E+04	3.33E+02	4.51E+00	3.93E+00
Right Colon Cont.	3.02E+04	5.05E+03	1.55E+04	1.99E+03	2.85E+01	2.75E+01
Left Colon Content	3.02E+04	7.94E+03	7.94E+03	2.39E+03	3.58E+01	3.53E+01
Rectosigm.Cont.	3.02E+04	1.05E+04	4.08E+03	2.49E+03	3.93E+01	3.90E+01

shared f_A

Compartment	^{90}Sr	^{90}Y	^{234}Pu	^{234}Np	^{230}U	^{226}Th
Oral Content	1.20E+01	4.33E-04	1.20E+01	2.47E-04	3.33E-06	1.49E-08
Oesophagus fast	6.30E+00	3.60E-04	6.30E+00	2.05E-04	2.77E-06	1.50E-08
Oesophagus slow	4.00E+00	6.26E-04	4.00E+00	3.56E-04	4.81E-06	7.57E-08
Stomach Content	4.20E+03	5.27E+01	3.85E+03	2.76E+01	3.75E-01	2.29E-01
SI Content	1.01E+04	4.19E+02	1.00E+04	3.33E+02	4.60E+00	4.00E+00
Right Colon Cont.	3.02E+04	4.59E+03	1.55E+04	1.99E+03	2.88E+01	2.78E+01
Left Colon Content	3.02E+04	7.54E+03	7.94E+03	2.39E+03	3.61E+01	3.56E+01
Rectosigm. Cont.	3.02E+04	1.02E+04	4.08E+03	2.49E+03	3.95E+01	3.93E+01

Following these computations examples from ICRP Publication 100 using the possibility of more complex biokinetics were also calculated:

First the case of absorption from different sites of the tract was considered. For iodine it was assumed that about half of the absorption takes place in the stomach.

For ^{131}I the numbers of transformations in the HATM compartments were calculated assuming that half of iodine in the stomach is absorbed directly to blood and 0.98 of iodine present in the small intestine contents is absorbed directly to blood. The results of these calculations are shown in Table 4.

Table 4: Numbers of disintegrations in the HATM for intake of 1 Bq ^{131}I with the assumption of absorption from the stomach and the small intestine contents

Compartment	^{131}I
Oral Content	1.20E+01
Oesophagus fast	6.30E+00
Oesophagus slow	4.00E+00
Stomach Content	2.10E+03
SI Content	1.44E+02
Right Colon Content	4.13E+02
Left Colon Content	3.96E+02
Rectosigmoid Content	3.80E+02

As a further example retention and recycling in the small intestine wall was considered in an example for ^{59}Fe given in ICRP Publication 100. The numbers of nuclear transformations and the faecal excretion rates were calculated with the parameters $\lambda_{SI,SI}$ wall = 3 d^{-1}, $\lambda_{SI\ wall,SI}$ = 0.3075 d^{-1}, $\lambda_{SI\ wall,blood}$ = 0.1025 d^{-1} und $\lambda_{SI,RC}$ = 3 d^{-1}. The results of these more complicated calculations are shown in Table 5.

The Table also shows results of computations performed with the simplified model presented in ICRP Publication 100 as "equivalent" to the Fe model given above. This simplified model includes direct absorption from the small intestine contents into the blood (f_A=0.2) and avoids recycling in the small intestine wall: another fraction of 0.2 of the small intestine content is taken up to the small intestine wall and is removed with a biological half-time of 3 d to the right colon content. The calculations showed that the numbers of transformations in the colon compartments are approximately the same in both models but the numbers of transformations in the small intestine contents and wall are underestimated by the simplified model by about 60% while the faecal excretion rates differ by up to 37% with the excretion rates being higher in the first 2 days and lower the following days for the simplified model. On the other hand, the fact that the recycling structure of the HATM could be implemented correctly by various institutions indicates that there is no need for a simplification of the HATM.

Table 5: Numbers of disintegrations and excretion rates for intake of 1 Bq ^{59}Fe with the assumption of recycling in the small intestine wall and with the simplified model

Compartment	number of transformations		Percentage deviation
	recycling model	simple model	simple model
Oral Content	1.20E+01	1.20E+01	-
Oesophagus fast	6.30E+00	6.30E+00	-
Oesophagus slow	4.00E+00	4.00E+00	-
Stomach Content	4.20E+03	4.20E+03	-
SI Content	2.24E+04	8.62E+03	-62%
SI Wall	1.58E+05	6.99E+04	-56%
Right Colon Content	3.34E+04	3.37E+04	+0.9%
Left Colon Content	3.31E+04	3.34E+04	+0.9%
Rectosigmoid Content	3.29E+04	3.32E+04	+0.9%
day after ingestion	daily excreted fraction of ingested activity in faeces		Percentage deviation
1	1.08E-01	1.48E-01	+37%
2	2.54E-01	2.92E-01	+15%
3	1.51E-01	1.48E-01	-2.0%
4	7.47E-02	6.07E-02	-19%
5	4.33E-02	3.00E-02	-31%
6	2.98E-02	1.92E-02	-36%
7	2.21E-02	1.41E-02	-36%
8	1.68E-02	1.09E-02	-35%
9	1.29E-02	8.46E-03	-34%
10	9.85E-03	6.61E-03	-33%

2.2 QA in model formulation

Model implementation work is also a very efficient means of quality assurance for the model description. Besides the inconsistency in ICRP Publication 100 [1] mentioned above some inconsistencies concerning total and regional absorption fractions were discovered in the draft ICRP text during the implementation of the HATM.

In the new HATM, absorption to blood is possible not only from the small intestine contents as in the old GI tract model [3] but from almost all regions of the tract. Therefore, the fraction absorbed from the tract to blood which was called f_1 in the old gastro-intestinal tract model is now called f_A in the new HATM and this total fraction absorbed to blood may be described by an expression of several regional absorption fractions. In the former draft ICRP text and its formulas it was not unambiguous if these regional fractions were related to the amount of intake to the tract (which is the case in the final model, i.e. f_A is the sum of all regional absorption fractions) or if they were related to the amount transferred to the respective absorption sites. Relevant comments were directed to the ICRP HATM Task Group and the text and its formulas could be corrected before going into press. It may be noted that, as an effect of this new concept,

f_A may now differ for ingested and inhaled material in cases involving absorption from the oral cavity because the intake of inhaled material to the tract takes place beyond the oral cavity into the oesophagus.

3 WOUND MODEL

The United States National Council on Radiation Protection and Measurements (NCRP) [2] developed and published a new biokinetic wound model which is described by five compartments and removal from the wound site by transport directly into blood or via the regional lymph nodes into blood, see Fig. 2.

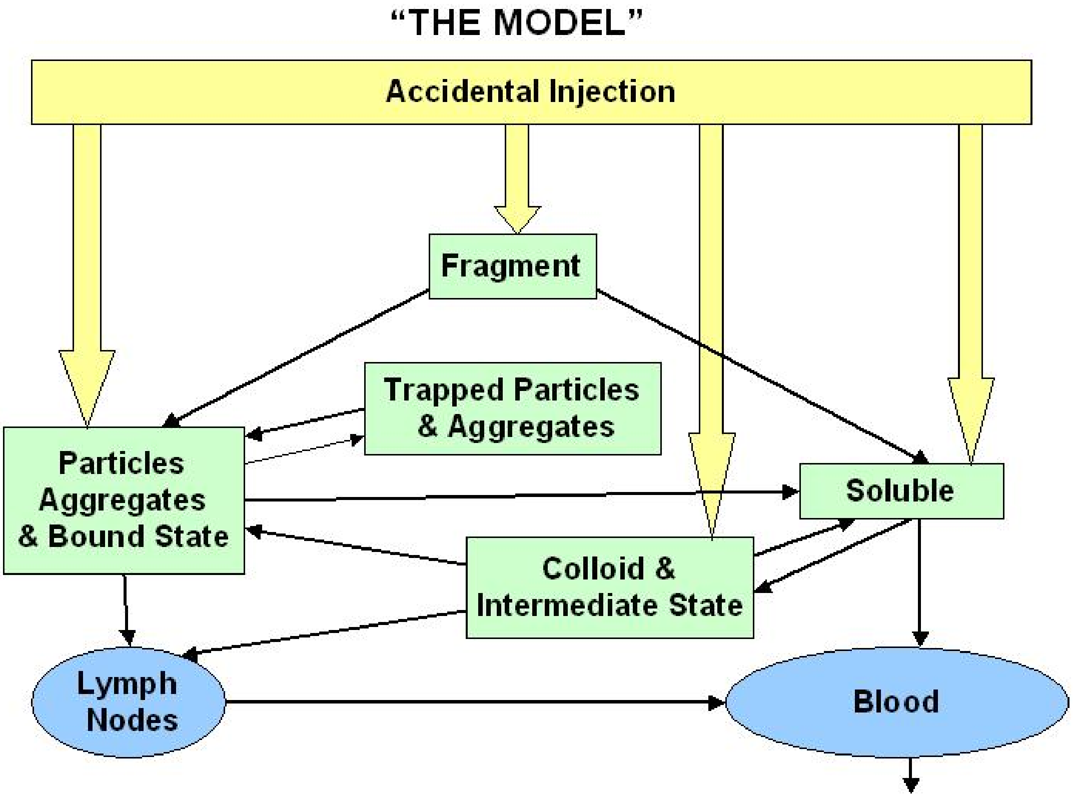
"THE MODEL"
Accidental Injection
Fragment
Trapped Particles & Aggregates
Particles Aggregates & Bound State
Soluble
Colloid & Intermediate State
Lymph Nodes
Blood

Fig. 2: NCRP wound model

This NCRP model defines seven default wound retention categories which are to be used according to the material involved: There are four categories for soluble material (with weak, moderate, strong and avid retention at the wound site) and categories for colloids, particles and fragments (which are large particles of more than 20 µm diameter). There are different uptake compartments for soluble material, colloids, particles and fragments and for each of these default categories only some of the five wound compartments are used.

3.1 Results of calculations

This model was implemented into codes of BfS, HPA, IRSN, University of Milan/Helmholtz Zentrum München, ENEA-Bologna, and Research Center Karlsruhe.

First, wound retention was calculated for all seven default categories for the relatively short-lived ^{131}I and for the long-lived ^{239}Pu using parameter values as given by the model developers to our group (see Table 6). There was very good agreement in the results for ^{239}Pu; for ^{131}I, however, there were discrepancies of up to about 10% due to the use of different half-lives (8d, 8.02d, and 8.04d). The results for ^{239}Pu are given in Table 7. They show a very wide range of wound retention characteristics for the seven default categories: While for the weakly retained soluble material only 0.0017% is retained in the wound after 100 d, for the fragments 96.6 % would still be retained after 10,000 d without medical intervention.

It has been seen that the long-term retention is much lower for the avidly retained soluble category than for the strongly retained soluble category, in contrast to expectations. The parameters for the soluble avidly retained category recommended in the printed NCRP document, available after the calculations presented here, are indeed different from those originally given to the group.

Table 6: Draft transfer rates of the NRPB wound model. CIS, colloid and intermediate state; PABS, particles aggregates and bound state; LN, lymph nodes

Transfer	Transfer rate (d^{-1})						
	Weak	**Moderate**	**Strong**	**Avid**	**Colloid**	**Particle**	**Fragment**
Soluble → Blood	45	45	0.67	0.4	0.5	100	–
Soluble → CIS	20	30	0.6	2.5	2.5	–	–
CIS → Soluble	2.8	0.4	0.024	0.0	0.025	–	–
CIS → PABS	0.25	0.065	0.010	160	0.05	–	–
CIS → LN	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	$2 \cdot 10^{-3}$	–	–
PABS → Soluble	0.08	0.02	0.0012	0.03	0.0015	$2 \cdot 10^{-4}$	0.0
PABS → LN	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	$4 \cdot 10^{-4}$	$3.6 \cdot 10^{-3}$	0.004
PABS → TPA	–	–	–	–	–	0.04	0.7
TPA → PABS	–	–	–	–	–	0.0036	0.0005
LN → Blood	–	–	–	–	0.03	$6 \cdot 10^{-4}$	0.03
Fragment → Soluble	–	–	–	–	–	–	0.0
Fragment → PABS	–	–	–	–	–	–	0.008

Table 7: Fractions of intake retained at the wound site Wound retention for the seven default categories of the NCRP wound model [2]

Days	soluble				Colloid	Particles	Fragments
	weak	moderate	strong	avid			
1	6.75E-02	3.19E-01	6.20E-01	8.68E-01	9.95E-01	9.96E-01	1.00E+00
2	3.55E-02	2.57E-01	5.10E-01	8.58E-01	9.89E-01	9.92E-01	1.00E+00
3	2.97E-02	2.11E-01	4.75E-01	8.54E-01	9.84E-01	9.89E-01	1.00E+00
4	2.72E-02	1.77E-01	4.62E-01	8.51E-01	9.79E-01	9.86E-01	1.00E+00
5	2.51E-02	1.52E-01	4.54E-01	8.47E-01	9.74E-01	9.83E-01	1.00E+00
6	2.33E-02	1.32E-01	4.47E-01	8.44E-01	9.69E-01	9.80E-01	1.00E+00
7	2.15E-02	1.18E-01	4.42E-01	8.40E-01	9.65E-01	9.77E-01	1.00E+00
8	1.99E-02	1.07E-01	4.37E-01	8.37E-01	9.61E-01	9.74E-01	1.00E+00
9	1.85E-02	9.84E-02	4.31E-01	8.33E-01	9.56E-01	9.72E-01	1.00E+00
10	1.71E-02	9.17E-02	4.27E-01	8.30E-01	9.52E-01	9.69E-01	1.00E+00
20	7.90E-03	6.51E-02	3.82E-01	7.96E-01	9.21E-01	9.48E-01	9.99E-01
30	3.65E-03	5.37E-02	3.46E-01	7.64E-01	9.02E-01	9.35E-01	9.99E-01
40	1.69E-03	4.47E-02	3.18E-01	7.34E-01	8.87E-01	9.26E-01	9.99E-01
50	7.82E-04	3.73E-02	2.94E-01	7.03E-01	8.76E-01	9.19E-01	9.98E-01
60	3.62E-04	3.11E-02	2.76E-01	6.75E-01	8.67E-01	9.13E-01	9.98E-01
70	1.67E-04	2.59E-02	2.60E-01	6.48E-01	8.59E-01	9.10E-01	9.97E-01
80	7.74E-05	2.16E-02	2.47E-01	6.21E-01	8.52E-01	9.05E-01	9.97E-01
90	3.58E-05	1.80E-02	2.36E-01	5.96E-01	8.45E-01	9.02E-01	9.97E-01
100	1.66E-05	1.50E-02	2.28E-01	5.73E-01	8.38E-01	8.99E-01	9.97E-01
200		2.43E-03	1.85E-01	3.79E-01	7.76E-01	8.73E-01	9.95E-01
300		3.90E-04	1.66E-01	2.52E-01	7.18E-01	8.48E-01	9.94E-01
400		5.98E-05	1.51E-01	1.67E-01	6.64E-01	8.24E-01	9.94E-01
500		9.18E-06	1.37E-01	1.10E-01	6.15E-01	8.00E-01	9.93E-01
600		1.41E-06	1.24E-01	7.30E-02	5.70E-01	7.77E-01	9.93E-01
700		2.10E-07	1.13E-01	4.83E-02	5.27E-01	7.55E-01	9.92E-01
800		3.23E-08	1.03E-01	3.20E-02	4.88E-01	7.33E-01	9.92E-01
900			9.33E-02	2.12E-02	4.52E-01	7.12E-01	9.92E-01
1000			8.47E-02	1.40E-02	4.19E-01	6.92E-01	9.92E-01
2000			3.25E-02	2.28E-04	1.93E-01	5.18E-01	9.89E-01
3000			1.25E-02	3.70E-06	8.94E-02	3.87E-01	9.86E-01
4000			4.77E-03	5.93E-08	4.13E-02	2.89E-01	9.83E-01
5000			1.83E-03		1.91E-02	2.17E-01	9.81E-01
6000			7.01E-04		8.80E-03	1.62E-01	9.78E-01
7000			2.69E-04		4.06E-03	1.21E-01	9.75E-01
8000			1.03E-04		1.88E-03	9.06E-02	9.72E-01
9000			3.95E-05		8.66E-04	6.77E-02	9.69E-01
10000			1.52E-05		4.00E-04	5.07E-02	9.66E-01

3.2 Comparison of results with approximation functions

NCRP also gives wound retention functions for the seven default categories as sums of up to three exponential terms. Our results obtained by use of the transfer rates given in the report were compared to those obtained by the use of these sums of exponential functions. Table 8.1 shows the ratios of the results of the approximation functions to the model predictions. It can be seen that there are major differences in some cases especially for the soluble categories. However, in the case of the avidly retained soluble materials the transfer rates in the printed report have been changed giving higher retention values at longer times after wound contamination. In the case of colloids it was observed by our group that the retention values due to the sum of exponential terms were close to those which were obtained using the "soluble" compartment as the input compartment instead of the "colloid & intermediate state" compartment.

Table 8.1: Ratio of the wound retention as calculated with the retention function to the wound retention values obtained with the model

Days	soluble				Colloid	Particles	Fragments
	weak	moderate	strong	avid			
1	0.68	0.97	1.09	1.00	0.86	1.00	1.00
2	1.15	0.87	1.08	0.99	0.85	1.00	1.00
5	1.21	0.79	1.02	1.00	0.85	1.00	1.00
10	1.08	0.92	0.98	1.01	0.85	1.01	1.00
20	0.86	1.03	0.94	1.05	0.85	1.01	1.00
50	0.43	0.99	0.87	1.15	0.85	1.02	1.00
100	0.14	0.90	0.86	1.34	0.86	1.02	1.00
200		0.75	0.89	1.84	0.86	1.00	1.00
500		0.49	0.89	4.68	0.88	0.97	1.00
1000			0.87	22.3	0.91	0.92	1.00
2000			0.83	505	0.98	0.82	0.99
5000			0.74		1.22	0.59	0.98
10000			0.60		1.76	0.34	0.96

Due to the fact that for each default retention category only few compartments (up to three) of the wound model are used, it was considered that it would be possible to calculate the analytical solution of the model as a sum of up to three exponential functions

$$R(t) = \sum_i a_i \cdot e^{-\lambda_i t}$$

which would be identical to the "exact" solution of the model. For the calculation of the wound retention function of a specified radionuclide the corresponding decay constant has to be considered additionally in the exponent. The coefficients a_i and λ_i of these exponential expressions were calculated and are given in Table 8. Similarly

$$R(t) = \sum_i a_i \cdot e^{-\lambda_i t}$$

which would be identical to the "exact" solution of the model. For the calculation of the wound retention function of a specified radionuclide the corresponding decay constant has to be considered additionally in the exponent. The coefficients a_i and λ_i of these exponential expressions were calculated and are given in Table 8.2 Similarly it is possible to give the "exact" output functions to lymph nodes and blood as sums of exponential functions. These will be calculated at a later time outside the CONRAD project.

Table 8.2: Coefficients a_i and λ_i of the exponential functions describing the wound retention of the NCRP wound model

	a_1	λ_1	a_2	λ_2	a_3	λ_3
weak	0.6734	65.89	0.2897	2.16	0.0369	0.077
moderate	0.5974	75.16	0.3099	0.306	0.0927	0.018
strong	0.518	1.28	0.261	0.023	0.221	9.60E-04
avid	0.1888	37.03	0.0007	10	0.8105	9.70E-04
colloid	0.0966	0.057	0.9048	7.70E-04	-0.0014	3.02
particle	0.075	0.047	0.925	2.90E-04	0	100
Fragment	0.9947	2.84E-06	0.0054	8.00E-03	-0.0001	7.00E-01

4 SYSTEMIC MODELS

It was planned to perform calculations with the new systemic ICRP models which are being developed for the revision of ICRP Publications 30, 54, 68, and 78 [4-7] to assess the impact of these new models as well as to be able to make a quality assurance (QA) of the model formulation. However, during the time when the CONRAD project was running these models were not yet finalised. Nevertheless, a few new models were implemented and their results were compared to those obtained with the former models. Further examples will be given in chapter 5. Besides the implementation of systemic models there were also considerations on their use resulting in the proposal of a skeleton/liver partitioning factor (4.3) as a tuning parameter.

4.1 Results of polonium calculations

Due to the London (and Hamburg) polonium incorporation cases the biokinetics of polonium (Po) were of special interest. Leggett and Eckerman [8] published a new systemic Po model (see Fig. 3) which was implemented by several institutions. This model has different input compartments for wound contamination and inhalation (plasma 2) and for ingestion (plasma 1) because of lower early excretion rates for ingestion. However, the reason for this may be a slower absorption process from the alimentary tract due to retention in the gut walls.

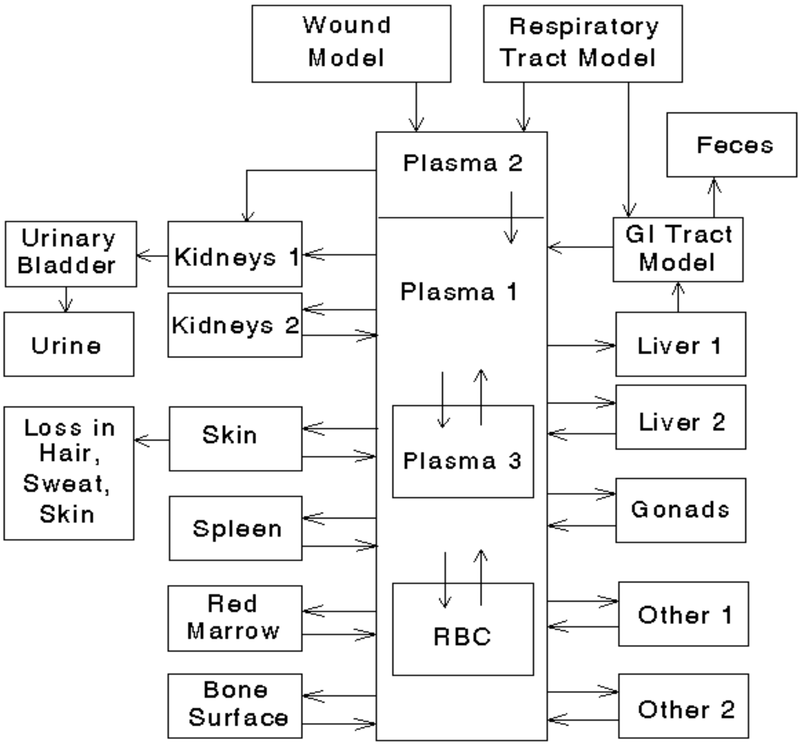

Fig 3: Biokinetic model for polonium [8]

The numbers of transformations are listed in Table 9. Compared to the present ICRP model there are less disintegrations in the source organs liver, kidneys and spleen; on the other hand, bone surfaces, skin and gonads were not included as source organs into the present ICRP model.

Table 9: Numbers of disintegration after injection of 1 Bq ^{210}Po predicted by the biokinetic model of Leggett and Eckerman [8]

Blood	6.45E+04
Liver	1.92E+05
Testes	3.51E+03
Other tissues	2.06E+05
Kidneys	5.06E+04
Urinary bladder content	2.69E+02
Skin	1.76E+05
Spleen	1.28E+04
Red marrow	2.55E+04
Bone surfaces	3.54E+04

4.2 Results of three plutonium model calculations

For plutonium (Pu) ICRP [9] published a recycling model based on the structure of an americium model by Leggett [10]. This Pu model will be revised in the forthcoming revision of ICRP Publications 30, 54, 68, and 78 [4-7], probably on the basis of a later paper by Leggett *et al.* [11]. Luciani and Polig [12] also proposed a model for Pu with a similar structure but with age-dependent transfer rates within the skeleton also during adulthood. These three models were implemented by four institutions, and the numbers of transformations were calculated. These results are given in Table 10, for the age-dependent Luciani model the numbers of transformations integrated over 50 years are given for two different ages at intake (25y and 45y).

Because in the Luciani and Polig model only the transfer rates within the skeleton compartments are age-dependent (between age 35 and 60) there are only differences of more than 10% for some bone compartments comparing the results for intakes at age 25 y and at 45 y. For bone surfaces the numbers of transformations are similar in all models; significant differences are observed for trabecular marrow, kidneys, testes, and other soft tissues (higher numbers in the model of Luciani and Polig) and in bone volume and cortical marrow (lower numbers in the model of Luciani and Polig).

The intercomparison of results showed very good agreement also for the age-dependent model of Luciani and Polig even if different computation approaches were used. While most of the institutions compiled the exact model with time-dependent transfer rates, the DOSAGE code of BfS used a step-wise approximation with constant transfer rates between the steps which were 1 y in this example.

The results showed no large differences between the present ICRP model and the model of Leggett *et al.* while the model of Luciani and Polig produced differences up to a factor of four (for example the numbers of transformations in red bone marrow) compared to the present ICRP model. On the other hand the age-dependence of this model does not influence the results very much: The differences between the assumption of an intake at age 25 y compared to 45 y were mostly of the order of 10%.

Table 10: Number of disintegrations after injection of 1 Bq ^{239}Pu according to the Pu models of Leggett *et al.* [11], ICRP Publication 67 [9] and Luciani and Polig [12] for ages 25 y and 45 y at intake

	Leggett	ICRP 67	Luciani and Polig	
			25y	45
ST1	7.63E+06	3.75E+07	9.15E+07	9.80E+07
ST0	1.36E+06	1.82E+05	2.24E+06	2.38E+06
ST2	7.85E+07	6.54E+07	1.41E+08	1.55E+08
blood 1 / blood	5.82E+05	4.55E+05	1.12E+06	1.20E+06
blood 2	3.75E+03	-	-	-
liver 0	5.82E+06	-	-	-
liver 1	1.37E+08	4.58E+07	1.29E+07	1.38E+07
liver 2	3.00E+08	3.26E+08	2.91E+08	3.14E+08
testes	3.83E+05	4.59E+05	1.06E+06	1.16E+06
cortical bone volume	6.09E+07	8.68E+07	2.81E+07	2.59E+07
cortical bone surface	3.38E+08	3.49E+08	3.96E+08	3.40E+08
cortical marrow	4.28E+06	4.68E+06	1.26E+07	1.37E+07
trabecular bone volume	4.19E+07	5.42E+07	3.78E+07	2.96E+07
trabecular bone surface	1.13E+08	1.15E+08	1.19E+08	9.35E+07
trabecular marrow	1.00E+07	1.09E+07	4.32E+07	4.62E+07
renal tubules / urinary path	2.58E+05	2.12E+05	1.09E+06	1.16E+06
other kidney tissue	1.31E+06	1.04E+06	2.54E+06	2.72E+06
urinary bladder content	2.21E+03	2.22E+03	1.81E+03	1.93E+03
small intestine content	8.96E+02	1.01E+03	8.60E+02	9.17E+02
right colon content	6.05E+03	5.98E+03	7.07E+03	7.53E+03
left colon content	6.05E+03	5.98E+03	7.07E+03	7.53E+03
rectosigmoid colon content	6.05E+03	5.98E+03	7.07E+03	7.53E+03

4.3 Skeleton/liver partitioning factor

In the development of biokinetic models for plutonium and other actinides, parameters for the description of the activity burden in the liver and skeleton are often used, particularly in mathematical expressions with a ratio of these two quantities [13-15]. The advantage is to summarise the main characteristics of the initial distribution of the plutonium uptake within the two main organs of deposition with a parameter that is only partially influenced by the initial scenario of contamination (path and time pattern of intake, physical and chemical characteristics of the compound, etc.). This is particularly useful when developing models on the basis of data sets obtained from several different studies, most of the time not specifically designed for model development purposes, as in the case of data from occupational exposure cases.

A parameter normally used to characterize the partitioning between liver and skeleton is the “partitioning factor”, often referred to the skeleton. It is defined as:

$$p_{Skel} = \frac{f_{Skel}}{f_{Skel} + f_{liv}} = \frac{f_{Skel}}{f_{tot}} \quad \Rightarrow \quad p_{Skel} \in [0,1]$$

where f_{skel} and f_{liv} are the fractions of activity distributed from the blood to the whole skeleton and liver, respectively. The p_{skel} factor varies between 0 and 1. Other expressions may also be used, e.g. a simple ratio of the skeleton to the liver burden or vice versa, and the values referred to these quantities may be easily converted to the expression given above. The expression defined here has the advantage of enabling study of the behaviour of the model by tuning the factor within a limited range, avoiding the setting of the factor to undetermined large values, as in the case of a simple ratio among the two organ burdens when the denominator value approaches zero.

This parameter has the values 0.63, 0.77, and 0.33 for the models of ICRP Publication 67 [9], Luciani and Polig [12], and Leggett *et al.* [18]. However, this value is related to a specific model and it cannot be used for the comparison of different models.

Keeping constant the value of the total deposition on skeleton and liver (f_{tot}), the tuning of the p_{skel} parameter will modify only the distribution of activity between skeleton and liver without affecting the distribution to the other organs: This will avoid the re-computation of all the fractions of plutonium distributed to the other organs and tissues.

The tuning of the p_{skel} factor affects the initial fraction distributed to the liver and the skeleton. In order to investigate the possible effects on the bioassays of interest (excretion functions for occupational exposure monitoring, activity burdens in organs in case of autopsy) and on the dose coefficients, simulations have been carried out. For a first analysis intake via injection is considered, to better emphasize the effects of the tuning of the p_{skel} factor. Other paths of intake, particularly via inhalation, are also shortly commented to point out the effects in case of more common scenarios of contamination for the occupational exposure.

In a sensitivity analysis with the ICRP 67 model [9] it has been shown that the 24h urinary excretion is not significantly affected. Much more significant is the variation of the 24h faecal excretion. In fact, according to the ICRP 67 model, 7% of the plutonium leaving the compartment Liver 1 is cleared to the small intestine and, therefore, mainly excreted through the intestinal tract to the faeces. The variation of p_{skel}, that significantly affects the liver retention, will also affect the faecal excretion: an increase of the p_{skel} value determines a decrease of the deposited fraction in the liver and, consequently, of the activity excreted in faeces. However, the decrease of the faecal excretion is generally smaller than the liver retention variation and it is observable only at later times as the faecal excretion of plutonium is due also to other processes, as the clearance from the blood directly to the upper large intestine.

In model development or in the first steps of a contamination analysis, the ratio of 24h urinary to 24h faecal excretion is often used. In Fig. 4 the variation of the ratio for different p_{skel} values is given. As consequence of the variation of the faecal excretion, the ratio may significantly change from the default value obtained for p_{skel} = 0.625, particularly in the time range 10 – 100 days post injection.

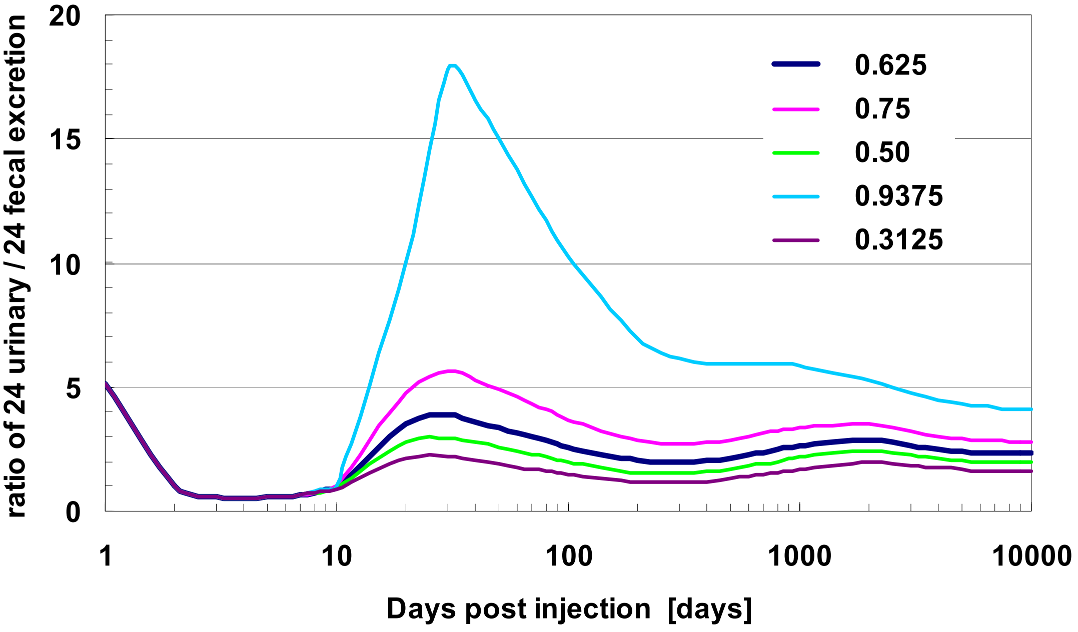

Fig. 4: Ratios of 24h urinary to 24h fecal excretion after injection for some p_{skel} values.

The faecal excretion of plutonium is significantly affected by a variation of the p_{skel} factor, particularly for all the situations with an instantaneous (injection) or quick (ingestion, inhalation with high lung absorption rate) transfer of activity to the systemic part. In these cases, even if the dose coefficient is only slightly affected by the variation of the p_{skel} factor, a dose assessment based on faecal excretion data, or on multiple data sets (e.g. urinary and faecal excretion data), may significantly vary.

5 STABLE ISOTOPE STUDIES

Investigations on the biokinetics of molybdenum (Mo), strontium (Sr), ruthenium (Ru) and zirconium (Zr) were conducted at the Helmholtz Zentrum München, in collaboration with the University of Milan, using stable isotopes as tracers. During the study enriched stable isotopes were administered intravenously and orally to healthy volunteers, and urine and blood plasma samples were collected at fixed times. The tracer concentrations in the biological samples were determined by means of Thermal Ionization Mass Spectrometry and/or Activation Analysis. The total number of studies performed is as follows:
Mo: 63 studies in 17 volunteers;
Sr: 74 studies in 13 volunteers;
Ru: 16 studies in 5 volunteers;
Zr: 23 studies in 12 volunteers.

5.1 Results of absorption to the HAT

The intestinal absorption of Mo was observed to be nearly complete (0.9) when given in liquid form, and to decrease for increasing amounts of administration. Absorption of molybdenum tracers was diminished to 0.6 when given with the diet. These values are in broad agreement with the f_1 value of 0.8 proposed by ICRP for workers [5] for compounds different from sulphides but less than the value of 1 proposed by ICRP for adult members of the public [9]. The evaluation of the Sr data showed that ingestion of different foodstuffs and nutritional factors could influence the fractional gut uptake of strontium. In contrast to the current ICRP value of 0.3 [9] the f_A value varied from 0.03 to 0.83 depending on the form of oral administration. Sr ingested with black tea showed the highest absorption rate, followed by water, cress, milk, salad, calcium solution, and baby food, while the lowest rate was found for strontium ingested with alginate in milk. For Zr the absorption was observed to be dependent on the chemical species administered, and f_A values of 0.001 and 0.0077 were derived for citrates and oxalates, respectively. These values are broadly in agreement with the f_1 value of 0.002 proposed by ICRP for workers [1] but lower than that of 0.01 proposed by ICRP for adult members of the public [16]. For all elements investigated, the time window in which the absorption rate reached its peak was between 40 and 120 minutes. The studies gave therefore no indication of a delayed absorption which could be ascribed to absorption in lower parts of the alimentary tract or due to retention in the walls.

5.2 Blood clearance and urinary excretion

Blood clearance of Mo was very rapid and could be described with a bi-exponential function with mean characteristic half-times of 30 min and of 6.6 h respectively. Systemic Mo was excreted in the urine mainly in the first 8-12 hours after entry into the transfer compartment, and the amount excreted was dependent on the total amount of circulating Mo.

The initial Sr plasma clearance measured after tracer administration was found to be much faster than predicted by the current ICRP model [9]. The biological half-time of the fast plasma clearance component was 0.25 hours in comparison to 1.1 hours used by ICRP. The urinary excretion in all subjects up to two days after tracer administration varied depending on the administered foodstuff in a wide range and differs from the ICRP model.

For Ru, blood clearance was highly dependent on the chemical species. Inorganic ruthenium was cleared with a characteristic time of 23 h, complexed ruthenium (citrate bound) was cleared with a characteristic time of 17 min. Systemic ruthenium is excreted in the urine mainly in the first 12 hours after administration. The 24-h cumulative excretion amounts to approx. 60% and 25% for complexed and inorganic ruthenium, respectively.

For Zr, the blood retention could be described by 2 exponentials with biological half-times of 3.8 h and 10.8 d, respectively, and was significantly different from the blood retention predicted by the present simple ICRP model [16].

No significant age or gender dependency of the absorbed fraction and of the urinary excretion was observed.

5.3 Proposal of new models

The results presented in sections 5.1 and 5.2 showed deviations from the predictions of the models currently recommended by ICRP. For the elements molybdenum and zirconium revised model structures, including recycling, had been developed (Giussani [17], Greiter [18]). In these models results of the stable isotope studies are coupled with other information related to long term retention. Within the framework of the CONRAD project the proposed models were implemented by several groups with good agreement in terms of numbers of transformations in the source organs.

For Mo a biokinetic model has been developed by Giussani [18], see Fig. 5: The systemic input compartment is the fast turnover transfer compartment from which Mo is excreted into urine or via liver into faeces or is transferred directly or via liver to the exchange transfer compartment. From this compartment it is excreted in urine via kidneys or it is transferred to kidneys and other tissues from where it is recycled to the exchange transfer compartment again.

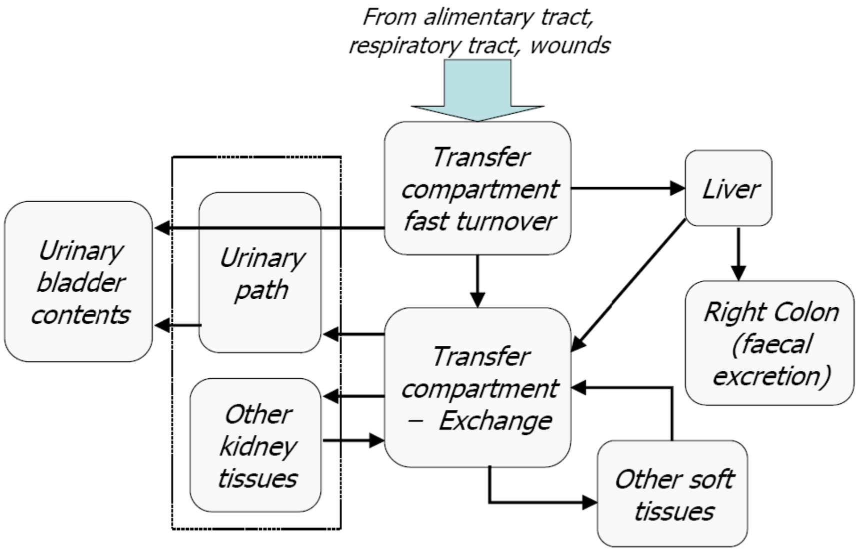
From alimentary tract, respiratory tract, wounds
Transfer compartment fast turnover
Liver
Urinary bladder contents
Urinary path
Right Colon (faecal excretion)
Transfer compartment – Exchange
Other kidney tissues
Other soft tissues

Fig. 5: Biokinetic model for Mo [17]

Table 11 shows the numbers of disintegrations after ingestion of ^{99}Mo including those for its daughter nuclides ^{99m}Tc and ^{99}Tc. These values are lower for liquids in the HAT compartments due to faster transit times in the upper part and due to the larger f_A value in the lower part. Because of the higher f_A value the numbers of disintegrations are higher in liver, kidneys and other tissues for liquids compared to diet. Ingestion doses calculated with this model are similar to those calculated with the present ICRP model [9] for the organs with the highest dose (liver and kidneys) as well as for the effective dose. On the other hand, doses to bone surfaces and red marrow are much lower with the new model because skeleton is no longer considered as a source region, in contrast to the current ICRP model.

Table 11: Numbers of disintegrations for ingestion of 1 Bq ^{99}Mo according to the Mo model of Giussani [17] and the HATM.

	^{99}Mo		**^{99m}Tc**		**^{99}Tc**	
	Liquids	**Diet**	**Liquids**	**Diet**	**Liquids**	**Diet**
Mouth	2.00E+00	1.20E+01	1.12E-04	4.03E-03	5.11E-14	1.84E-12
Oesophagus/1	4.50E+00	6.30E+00	8.83E-04	3.35E-03	4.03E-13	1.53E-12
Oesophagus/2	3.00E+00	4.00E+00	2.69E-03	5.82E-03	1.23E-12	2.68E-12
Stomach	1.79E+03	4.15E+03	8.59E+01	4.33E+02	5.73E-08	4.11E-07
Small intestine	1.43E+03	5.60E+03	1.21E+02	1.26E+03	9.00E-08	1.73E-06
Right Colon	4.00E+03	1.50E+04	2.27E+03	9.29E+03	2.11E-04	1.87E-04
Left Colon	3.55E+03	1.34E+04	2.76E+03	1.07E+04	2.25E-04	2.42E-04
Recto-Sigmoid	3.15E+03	1.19E+04	2.76E+03	1.05E+04	2.39E-04	2.95E-04
Transfer Compartment	1.11E+04	7.29E+03	3.56E+03	3.08E+03	7.33E-06	7.66E-06
TC-Exchange	1.33E+03	8.68E+02	6.13E+02	4.71E+02	1.23E-04	8.25E-05
Liver	7.43E+04	4.86E+04	6.71E+04	4.43E+04	6.60E-02	4.40E-02
Other tissues	8.64E+04	5.65E+04	7.82E+04	5.17E+04	4.31E-02	2.88E-02
Other Kidney Tissues	6.79E+03	4.44E+03	6.13E+03	4.05E+03	2.84E-03	1.89E-03
Urinary Path	7.71E+03	5.04E+03	5.90E+03	4.02E+03	8.78E-04	5.95E-04
Urinary Bladder	2.39E+03	1.56E+03	1.35E+03	9.84E+02	1.06E-04	7.14E-05

For Zr a biokinetic model has been developed by Greiter [18], see Fig. 6. It is a recycling model with the source tissue compartments bone and soft tissues and there is only urinary excretion.

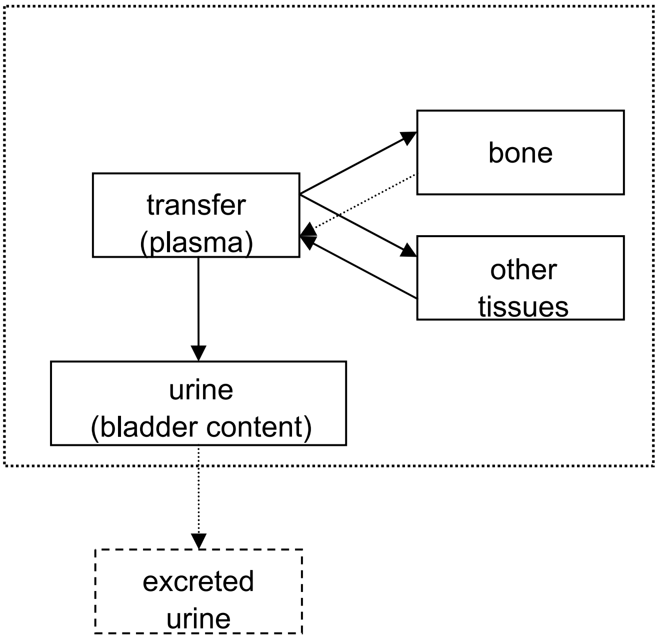

Fig. 6: Biokinetic model of Greiter [18] for Zr

Table 12 shows the numbers of disintegrations after ingestion for the parent nuclide ^{95}Zr for citrates and oxalates compared to the values obtained with the ICRP model [9]. In all computations the old ICRP GI tract model [3] was used. The numbers of transformations are a little higher for oxalates and significantly lower for citrates for bone and soft tissues than those obtained with the ICRP model. The largest organ doses are the doses to the large intestine compartments which are nearly the same for all models used here.

Table 12: Numbers of disintegrations after ingestion of 1 Bq ^{95}Zr with the ICRP model [9] and the model of Greiter [18] for citrates and oxalates

	number of transformations over 50 y		
source organ	ICRP	Greiter citrate	Greiter oxalate
ST content	3.60E+03	3.60E+03	3.60E+03
SI content	1.42E+04	5.99E+03	5.95E+03
ULI content	4.72E+04	4.76E+04	4.73E+04
LLI content	8.40E+04	8.48E+04	8.42E+04
bone surface	3.90E+04	6.49E+03	4.82E+04
other tissues	3.87E+03	5.87E+02	4.37E+03
blood	3.07E+02	5.96E+02	4.43E+03
UB content	2.68E+01	6.05E-01	4.50E+00

6 CONCLUSIONS

During the work of this group various biokinetic models have been implemented by several European institutions. QA procedures showed that these implementations were successful. This work also included a very useful QA of model formulation. Moreover, stable isotope experiments were assessed taking into account the new model structures. Finally new models were developed and the very important development of a new model for DTPA decorporation was started (see another contribution within this volume).

This work showed the importance of networking different insitutions and different computation approaches for assuring correct implementations of the biokinetic models and for discussing the use and the implications of these models. All the members of the group agree on the extreme usefulness of the work performed and therefore it is intended to continue it within a EURADOS working group.

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3.2.2.- CONRAD Task 5.2.2.: Towards a biokinetic model for DTPA-therapy

FINAL REPORT, FEBRUARY 2008

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CONRAD TASK 5.2.2.: TOWARDS A BIOKINETIC MODEL FOR DTPA-THERAPY

ABSTRACT

Within CONRAD TG 5. the development of a biokinetic model describing the mechanisms of decorporation of actinides by administration of DTPA was initiated. Administration of DTPA enhances the urinary excretion rate of Pu by about a factor of 50. The effect of the excretion enhancement can be seen over some days. On the other hand, DTPA is almost completely excreted in urine within a day. From a physiological point of view, DTPA might binds all Pu in extracellular fluids and does not enter cells but it has direct influence on Pu in the liver. The modelling process was started by using the systemic biokinetic model of Leggett et al.(2005) for Pu and the biokinetic model for DTPA compounds of ICRP Publication 53. The chelation of Pu and DTPA to Pu-DTPA was assumed to follow a second order process. It was assumed that the chelation takes place in the blood and in the rapid turnover soft tissues compartments of the Pu model, and that Pu-DTPA behaves in the same way as DTPA. First applications of this draft model showed that the height of the peak of the urinary excretion after administration of DTPA was determined by the chelation rate. However, repetitions of DTPA administration shortly after the first one showed no effect in the application of the draft model in contrast of data from real cases. The present draft model is thus not yet realistic. So several questions still have to be answered, notably about where the Pu-DTPA complexes are formed, which biological ligands of Pu are dissociated, if Pu-DTPA is stable, if the biokinetics of Pu-DTPA excretion is similar to that of DTPA. Further detailed studies of human contamination cases and experimental data about Pu-DTPA kinetics will be needed in order to be incorporated into the model.

CONRAD TASK 5.2.2.: TOWARDS A BIOKINETIC MODEL FOR DTPA-THERAPY

CONTENTS

1 Introduction 126
2 Biokinetic models for uncomplexed plutonium and DTPA 127
3 Models for chelation therapy in the literature 129
4 The CONRAD approach 132
5 Calculations with the model 136
  5.1 The influence of the K_R constant 136
  5.2 Model properties: Theoretical Scenarios 138
  5.3 Model Application: Case Studies 140
6 Conclusion and Perspective 143
7 Members of the DTPA Task Group 146
8 References 147

1 INTRODUCTION

This work is supported by the EC through the concerted action “A Coordinated Network for Radiation Dosimetry” (CONRAD) of the EURATOM 6th Framework Programme for research and training in nuclear energy (contract No FI6R-012684) as part of the task T5.2 “Research studies on biokinetic models” of CONRAD WP5. International experts outside CONRAD, especially from CEA and FZK, who are also involved in research studies about DTPA have been working with the group and made many important contributions to this on-going work. This report presents some of the group’s ideas and results from the many fruitful discussions at the meetings of the group held in Madrid (CIEMAT, 22nd January 2007), Karlsruhe (FZK, 14 -15th May 2007), Athens (GAEC, 17th October 2007) and Paris (IRSN, 21st January 2008).

The only treatment available after serious internal contamination with plutonium is a chelation therapy with DTPA (**D**iethylene **T**riamine **P**entaacetic **A**cid). Injection or Inhalation of DTPA formulations after plutonium incorporation enhances the urinary excretion of plutonium by forming stable and quickly excreted Pu-DTPA complexes (chelates) which are quickly eliminated into the urine (see e.g. Figure I). Thus, a radiation dose to the person in proportion to this additional decorporation of the contaminant is avoided. In order to quantify the achieved reduction of dose and to plan future treatment strategies a modelling of DTPA-therapy is needed. There are two different requirements to a model of decorporation therapy. Obviously one is the scientific urge to understand and optimize the processes involved. The other requirement to be met is an easy to use “hands-on” model, because physicians and health physicists involved in the therapies need guidance in interpreting the data available in order to reach the maximal dose reduction possible.

In dose assessments after incorporation of plutonium its urinary excretion is usually monitored and the observed rate is interpreted using biokinetic models. At the present time no reference or “standard” model for the biokinetics of Pu under the effect of decorporation therapy with DTPA is available. Several models for the systemic biokinetics of “pure” plutonium without the influence of decorporating agents are available in the literature. The latest model recommended by the ICRP was presented in Publication 67(1). Newer and more realistic models are available e.g. Luciani(2) or Leggett(3). Nevertheless excretion data, which are influenced by chelation therapy, cannot be interpreted using the present models, since the effect of DTPA is not taken into account. Thus a conservative estimate is usually performed. However, it would be good to estimate the dose reduction due to the treatment. The EURADOS/CONRAD TG5.2 and other international experts engaged in biokinetic modeling jointly addressed this issue and made an approach towards a biokinetic model of plutonium decorporation by DTPA which is presented here. The main principle is to consider the biokinetics of plutonium and DTPA separately and to explicitly assess the chelation-process. The current status and first results are presented in this report. This work is still under development and will be continued beyond the CONRAD framework.

The basic principle of decorporation therapy with chelating agents was stated in 1942 by Kety(4). The metal ion is mobilized by a complexing agent and the formed (stable) complex is no more available for the “standard” metabolic processes of the metal. Decorporation treatments using chelators have been done since the 1950s(5). DTPA has proved to be an “optimal” chelator for treatment of plutonium (and most transuranium Elements) incorporation cases. The urinary excretion of plutonium is enhanced for several days after the administration of DTPA. Thus the body burden is reduced. Lots of studies (mainly animal experiments) and case reports have been published, especially in the 1970s. In the framework of the IDEAS and the CONRAD projects a database including references to literature presenting incorporation cases (not only focused on plutonium) and a database including the reported data has been developed. Many of the known DTPA-treatment cases can be found in there(6). The cases used in building the model have been chosen from these databases.

Usually the trisodium salts of Ca- or Zn-DTPA are injected intravenously. As first measure powder formulations of DTPA are applied via inhalators (spinhaler) in some cases. Only sparse side actions of DTPA-therapy have been reported. Short-lasting irritations of the skin were observed in few cases. One case with repeated treatments of overall more than 500g DTPA showing no side effects of DTPA has been reported by Breitenstein(7). The efficacy of the treatment slightly depends on the amount of DTPA injected. The typical dosage used in treatments is 0.5g DTPA. This value has evolved empirically, but experts state that an optimized value would be between 0.25g and 0.5g DTPA(8,9,5). From a medical point of view the reduction or avoidance of a radiation dose from plutonium is important, because the reduction in the risk of induction of stochastic effects such as cancer or more severe deterministic effects is directly linked to the dose averted. Currently there are no “scientifically based rules” for an optimized treatment schedule. In-house protocols are used by the different institutions. Treatments are often repeated (e.g. daily) during the first few days and with some spare days over the first weeks as e.g. reported by CEA(10). In Karlsruhe the so called “diagnostic DTPA-treatment” (one single injection at the first day after incorporation) is used to elaborate the need for further treatment. Several papers reported an effectiveness of late (several weeks/months after incorporation) treatment(11). Having a generic model describing the effects of DTPA on the biokinetics of plutonium and other transuranium elements would help optimizing the treatment strategy and thus maximize the dose averted and minimize the health effects of the incorporation. This may become an important point even beyond the radiation protection of workers in the nuclear industry with reference to mass casualty scenarios with internal contamination of plutonium in the non-exposed population.

2 BIOKINETIC MODELS FOR UNCOMPLEXED PLUTONIUM AND DTPA

Research on the metabolism of plutonium in man is done since the 1940s. In blood plutonium binds to proteins, mainly transferrin. Plutonium circulates in blood and accumulates in liver and bones and is stored inside these compartments/the body for long times (order of magnitude: tens of years). Small amounts of the incorporated plutonium are excreted via urine and to a lesser extent in feces. Several models of the biokinetic behaviour of plutonium are available. The latest one was published by Leggett and co-workers in 2005(3). Blood is here represented by two, the liver by three and the skeleton by six compartments. This model is used in the CONRAD approach and will be discussed in more detail later.

(Metal)Complexes of DTPA are used in nuclear medicine for pulmonary or kidney imaging and cisternography. Non radioactive Gd-DTPA-complexes are used as contrast-agent in nuclear magnetic resonance imaging. A biokinetic model for the medical application of DTPA was published by the ICRP in 1987(12). The only model available for metabolism of “pure” DTPA was published by Stather et al. in 1983(13). ^{14}C-labelled DTPA was administered either by injection or by inhalation to human volunteers. Blood concentration and urinary excretion were monitored. 99% of the injected DTPA was excreted in the urine of the first 24 h after injection. A small but detectable amount was then excreted during one week, 0.1% on the 3rd day, 0.02% on the 7th day. Small amounts of DTPA were excreted in the feces. No mechanism enabling DTPA to cross cell boundaries and entering cells could be identified. According to the compartmental structure adopted by Stather et al., DTPA is distributed in plasma and extracellular fluids. The extracellular fluids are described by only one compartment, no distinction in interstititum, blood plasma and lymph was made. The group introduced this physiological knowledge in a new model of pure DTPA biokinetics. Stather and coworkers used both data from the inhalation and the injection studies to develop the model, and some approximation had to be introduced, especially when dealing with the complex mechanisms of transport and absorption of material in the respiratory tract. These approximations affected the model outputs, and the little contribution to urinary excretion after day 1 was not correctly described. In this work, only data after injection were used to find the parameters of the model. The model structure and the model parameters are given in Figure A and Table A.

DTPA is supposed to be directly excreted into the urine or to be transferred to the interstitium. From there it goes back to blood either directly or through the lymphatic circulation. From Figure B it can be observed that the current model is able to describe the measurement of DTPA both in blood and in urine, including the long-term excretion.

The coupling of this model with the biokinetic model for plutonium by Leggett et al., especially the correspondence between compartments and the identification of the tissues where chelation may take place, is still an open question, Therefore, in the following analysis a simpler model for DTPA and Pu-DTPA chelation was used, containing the same compartments as the Leggett model.

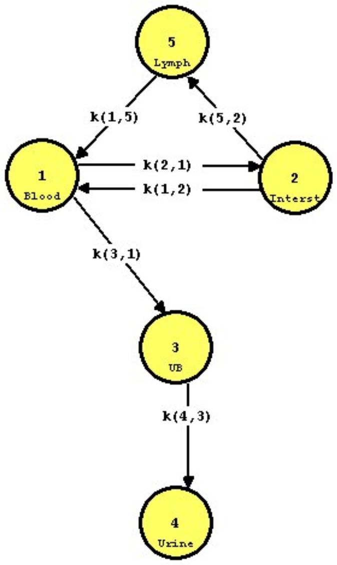


Figure A : Model structure for «pure» DTPA.

TRANSFER	VALUE (d^{-1})
Blood to Interstitium	145 ± 11
Interstitium to Blood	64 ± 4
Interstitium to Lymph	0.123 ± 0.012
Lymph to Blood	0.405 ± 0.036
Blood to urinary Bladder	45.7 ± 0.8

Table A : Model parameters for the CONRAD-model for “pure” DTPA

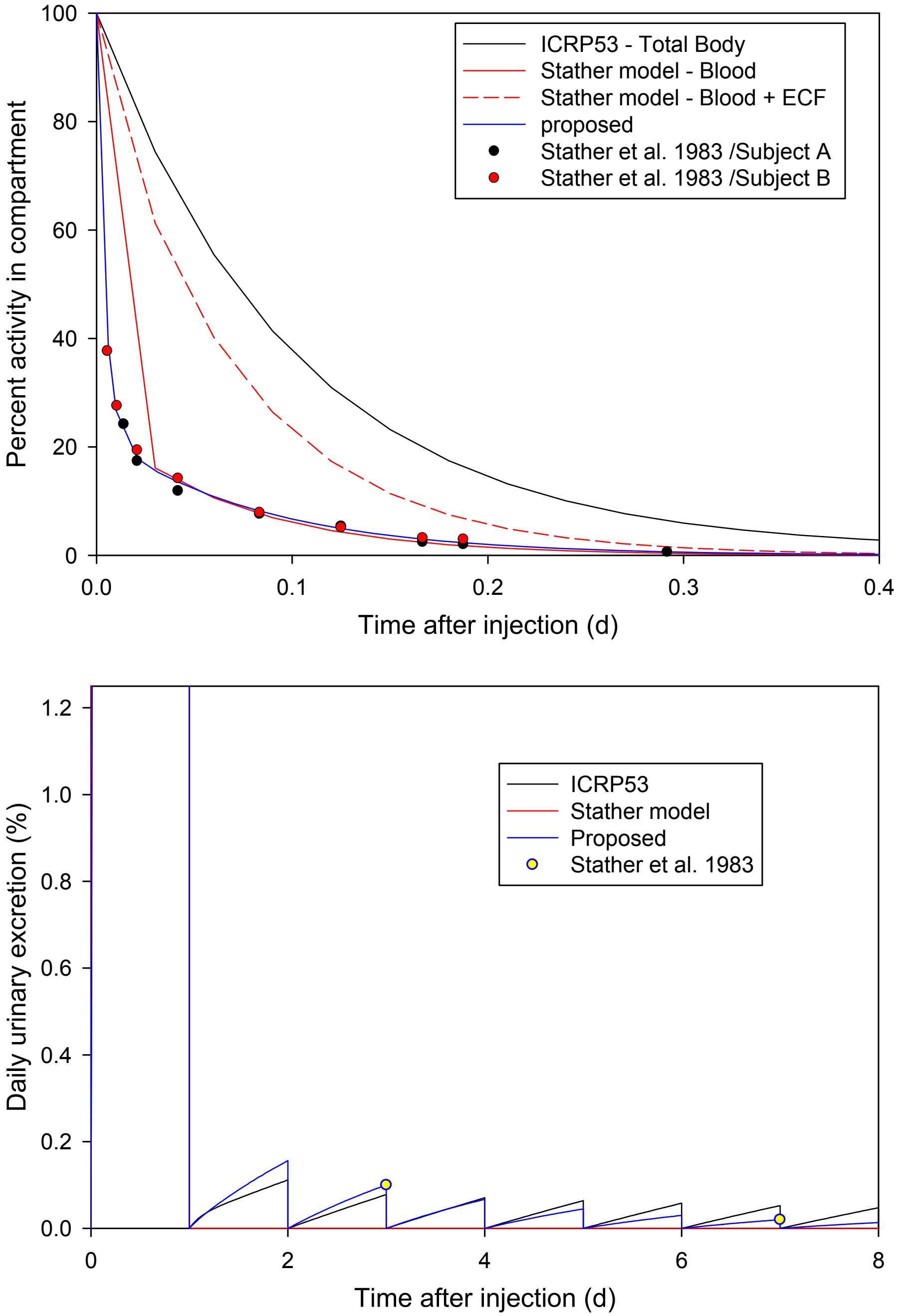


Figure B: Fit of the model outputs to the data from Stather(13).

3 MODELS FOR CHELATION THERAPY IN THE LITERATURE

Several approaches to the modeling of decorporation therapy can be found in the literature. A quick glimpse to the models and the underlying assumptions is presented here.

Jech(14) states that the effect of chelation has ceased 100 days after application of DTPA. Thus data sampled at long times after the infusions can be interpreted using the standard models. Only the reduced intake can be calculated with this "model"; the decorporation efficiency can not be described. Hall(15) developed an empirical model, which is able to calculate urinary excretion curves after chelation therapy. The basic assumptions of this model are(16):

- At the time t when the chelation agent is administered, there is a quantity *q* of plutonium that is available, or will be available in the following 24 hours, to form a chelate. The plutonium can come from any intake that may have occurred prior to the chelation.
- The chelate is stable, i.e., it will not separate back into plutonium and the chelation agent, and will be excreted with its own excretion function i_c, rather than that of plutonium i_u.
- The biokintetics of the plutonium that was not chelated will be unaffected by the chelation except the intake will appear to be reduced from *I* to *I-q*.

This model can be used to easily assess urinary data without getting involved into biokinetic modelling too deeply. But it can only give the overall reduction of effective dose, no information about the redistribution of plutonium after chelation and the dose reduction in the target-organs (liver, skeleton) is given by the model.

A simple mechanistic model was presented by LaBone(17). In his words:

- The structure of the ICRP 66/67 model suggests a simple and direct approach to modelling chelation therapy:
- Start the model with an inhalation intake at t=0 days.
- At the time of chelation, stop the model and remove some plutonium from the compartments where the Pu-DTPA chelate is assumed to form.
- Take this chelate and let it be excreted with its own excretion function (the same function used in Hall's method).
- Restart the model with the new compartment contents as if nothing had happened and calculate the urinary excretion of plutonium.
- Add the excretion of chelate and the excretion of plutonium to get the total excretion.

In a publication from Bailey(18) a compartmental model used for interpretation of a wound incorporation is presented. The chelator (DTPA) and the chelate (Pu-DTPA-complex) are connected to the Blood compartment of the ICRP plutonium-model and are assumed to be removed through urinary excretion with the same fractional clearance rate. Parameter values have been based on the work of Hall et al.(15) and adjusted to the data interactively. Fritsch(19) models decorporation therapy by adding up to three DTPA-compartments (associated with blood + ST0) clearing to urine to the different plutonium-models and fitting the rate constants. Each injection clears 90% of the plutonium in (blood + ST0) and 90% of the total amount of the daily dissolved plutonium from the wound which will reach the blood. Using such assumptions, good fits of simulations to biological data could be only obtained using Luciani's(2) or Leggett's(3) models. Good fits are obtained with these models as well as with the ICRP67(1) model assuming a variable decorporation of plutonium retained in the liver. James(20) applies multiplication factors to the rate-constants of the ICRP67(1) model to simulate the effect of chelation therapy in a USTUR donor. Besides the urinary excretion data, the organ contents from autopsy results are used in a least square fit of the new transfer coefficients.

Some of the models presented here have been designed for the interpretation of only one particular incorporation case. Thus they cannot be used to derive general predictions about the generic effects of DTPA application for the decorporation of plutonium. The aim of the group is to develop a generic model describing the biokinetics of plutonium under the effect of chelation therapy.

4 THE CONRAD APPROACH

The basic idea of the approach is to consider the biokinetics of plutonium and the injected Ca/Zn-DTPA separately and to connect them by a suitable mathematical description of the chelation process. Thus the model consists of three compartmental systems which will be represented in this report by the following variables:

- x[ ]: compartments representing DTPA-biokinetics
- y[ ]: compartments involved in plutonium-biokinetics
- z[ ]: compartments containing the Pu-DTPA-complex (which is formed in-vivo)

The values of interest (urinary/fecal excretion of plutonium) are then given by the sum of the corresponding values from the systems y and z. Usually biokinetic models in radiation protection are solved in units of activity (Bq). The DTPA-compartments have no activity and thus the group decided to use moles (mol) as basic units in all compartments. The conversion from the common units of g of DTPA and Bq of plutonium are(21,22):

- 1 mol of Ca-DTPA = 497.2 g
- 1 mol of Zn-DTPA = 522.7 g
- 1 Bq of ^{238}Pu = $6.6 \cdot 10^{-15}$ mol
- 1 Bq of ^{239}Pu = $1.8 \cdot 10^{-12}$ mol
- 1 Bq of ^{242}Pu = $5.0 \cdot 10^{-13}$ mol

The typical treatment dosage is 0.5 g or $1 \cdot 10^{-3}$ moles of DTPA. An incorporation of 1 kBq equals ~ $2 \cdot 10^{-9}$ moles of ^{239}Pu. Thus several orders of magnitude of difference between the systems need to be handled when solving the full model. This introduces numerical problems, which have been reported by most members of the group. The solver (algorithm and parameters) for the system of ordinary differential equations needs to be chosen carefully to achieve good results.

In a first approximation the same kinetics for the Pu-DTPA complexes formed inside the body and the administered (Zn- or Ca-) DTPA is assumed, which means that systems x and z share the same structure and the same transfer rates. This reduces the numbers of free parameters in the model. The biokinetics of the Pu-DTPA complex is supposed to be similar to other M-DTPA molecules, with a weak influence of the M atom (M = Ca, metals, lanthanides, actinides). However, it is known that DTPA is a long molecule of mass about 400 Da while Pu-DTPA has a spherical shape and a mass about 600 Da. Thus, they may not share exactly the same kinetics. The shared structure of the systems x and z may be split in the future development of the models. An equimolar reaction between plutonium and DTPA (complexation) is assumed for modelling purposes. For simplicity the complex is treated as being stable, so no backwards (dissolution/complex-breaking) reaction needs to be taken into account. This assumption is supported by the "high" stability constant of the Pu-DTPA chelate (compared to that of other Metal-DTPA-complexes) as reported in(5). The proposed "chemical reaction" is then given by:

$$\text{DTPA} + \text{Pu} \text{ ----> } \text{Pu-DTPA}$$

Obviously the reaction can only take place in compartments, where plutonium and DTPA are available. Thus the different systems x, y and z need to be harmonized for modeling purposes. The group agreed to use model of Leggett(3) and the ICRP 30 model of the gastro-intestinal tract(23) as description of plutonium metabolism (system y, figure C). However, it is noted that other models such as the Luciani and Polig(2) model or the new alimentary tract model(24) may be better depending on the situation. The structure of systems x and z has been adapted to the model of Leggett. First the compartments, in which the complexation takes place, were identified. DTPA is known to have no ability to cross cell boundaries and is distributed only in extracellular fluids. Circulating plutonium is defined as plutonium in blood plus rapid-turnover soft tissues (Compartment ST0) by the ICRP and Leggett. The Leggett model has two compartments "Blood1" and "Blood2" for representing blood. Both have a (strong) clearance to the urine via urinary bladder. The Blood2 compartment represents the plutonium recycled from the organs and clears rapidly into Blood1 from where the plutonium is transported to the organs. According to the author: "This provides a physically meaningful way of implementing the assumption that recycled plutonium has higher urinary clearance than the original input to blood."(3) The initial input of plutonium to blood is split between the Blood1 (70%) and the ST0 (30%) compartments.

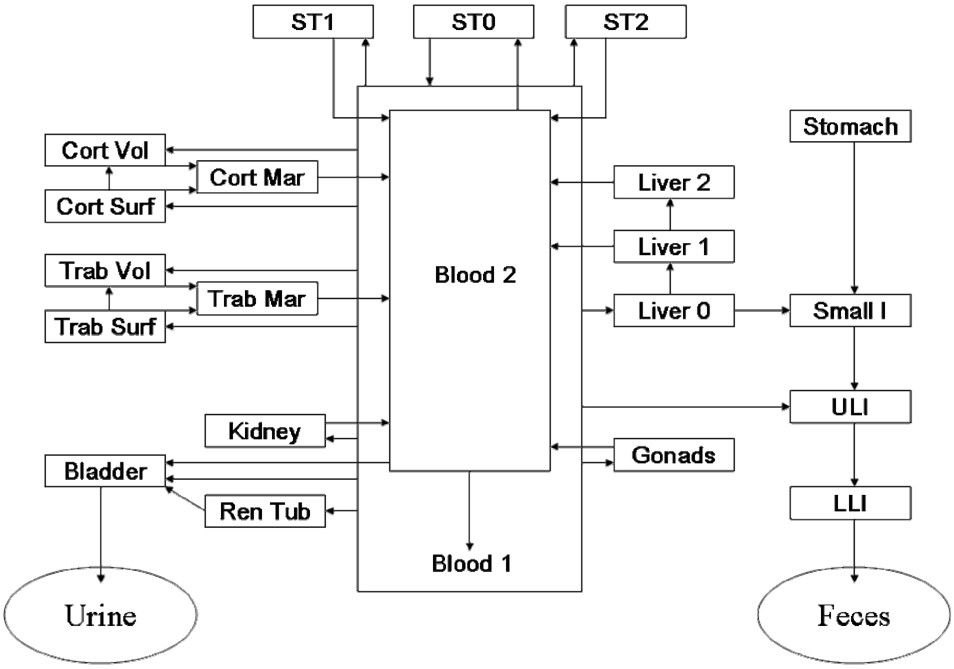


Figure C: Compartmental structure of System Y ("pure" plutonium) according to(3)

The structure of the model for DTPA and the Pu-DTPA-complex needs to represent blood, extracellular fluids and pathways to urinary and fecal excretion. The corresponding compartments in the Leggett model are Blood1, Blood2 and ST0. The Blood 2 compartment can not be reached by DTPA, because no inflow from organs is assumed. Thus this compartment is not used in systems x and z. Instead the ST0 compartment is directly connected to Blood 1 by in- and outflow. Excretion in urine is modeled via pathways to the bladder. To model the enhancement in fecal excretion a direct path from Blood 1 to ULI is included.. Probably a path including the liver (bile) must be assumed in future updates of the model.

The major route of plutonium excretion into the intestine is via the bile; the excretion is enhanced by DTPA(5). The value of f_1 (giving the fraction of absorption from the intestine walls) for the Pu-DTPA-complex needs to be discussed, several values ranging from 5% to 35% have been reported in literature (25,26,5). In the current version of the model this value is set to zero, which means no reabsorption of DTPA and Pu-DTPA from the GI-tract. The structure of the x and z-System chosen first is shown in Figure D. A further step will be using a representation of the pure DTPA-model as presented earlier in this paper. Other structures for this part of the model have been discussed by the group. The main issue in this on-going discussion is the representation of extracellular fluids in the model of Leggett. The meaning of compartment ST0, its relation with the extracellular fluids, the representation of the effect of DTPA in liver and skeleton are pending questions that will have to be investigated.

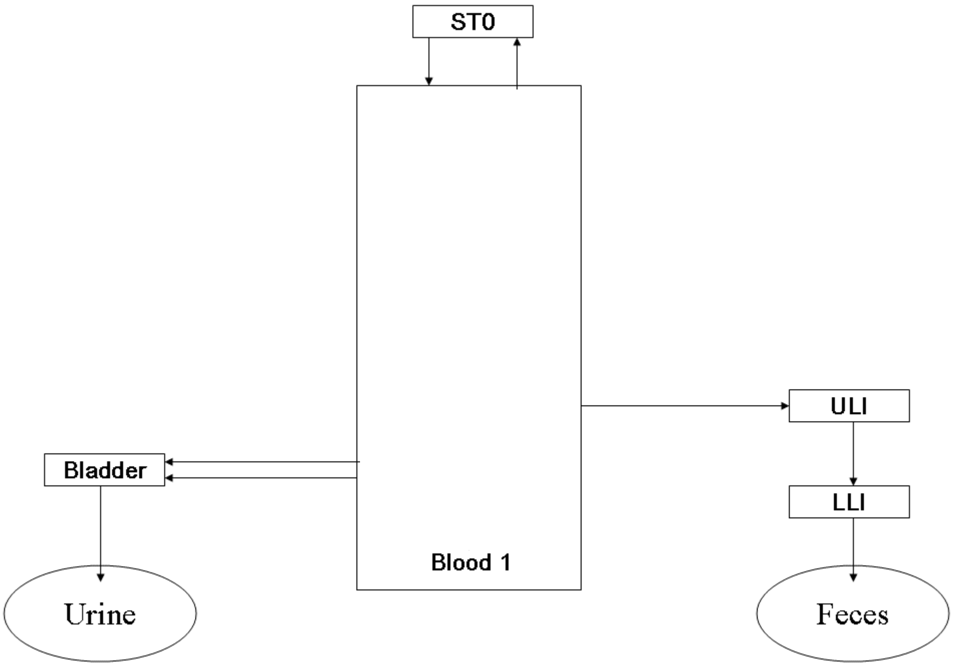


Figure D: Compartmental structure of Systems X and Z (DTPA and Pu-DTPA)

Baseline values for the transfer rates in the model(s) have been derived from literature(13) and data, but are still to be modified to fit as much data as possible. The starting values for developing the model are given in Table B. For convenience the values for the Pu-Model of Leggett(3) and the gastro intestinal tract model of ICRP 30(23) have been added to this table.

Systems	From compartment	To compartment	Transfer coefficient [d^{-1}]
X and Z	Blood 1	Bladder	53
X and Z	Blood 1	ULI	1
X and Z	Blood 1	ST 0	400
X and Z	ST 0	Blood 1	160
Y	Blood 1	Liver 0	4.6200E-01
Y	Blood 1	CS	8.7780E-02
Y	Blood 1	TS	1.2474E-01
Y	Blood 1	CV	4.6200E-03
Y	Blood 1	TV	1.3860E-02
Y	Blood 1	Bladder	1.5400E-02
Y	Blood 1	Renal Tubuli	7.7000E-03
Y	Blood 1	Other Kidney Tissues	3.8500E-04
Y	Blood 1	Testes (Ovaries)	2.6950E-04 (8.4700E-05)
Y	Blood 1	ST 1	1.8511E-02
Y	Blood 1	ST 2	2.3100E-02
Y	Blood 2	Bladder	3.5000E+00
Y	Blood 2	Blood 1	6.7550E+01
Y	Blood 2	ST 0	2.8950E+01
Y	ST 0	Blood 1	9.9000E-02
Y	ST 1	Blood 2	1.3860E-03
Y	ST 2	Blood 2	1.2660E-04
Y	Renal Tubuli	Bladder	1.7329E-02
Y	Bladder	Urine	1.2000E+01
Y	Other Kidney Tissues	Blood 2	1.2660E-04
Y	TS	TV	1.2300E-04
Y	TS	TM	4.9300E-04
Y	TV	TM	4.9300E-04
Y	CS	CV	2.0500E-05
Y	CS	CM	8.2100E-05
Y	CV	CM	8.2100E-05
Y	CM	Blood 2	7.6000E-03
Y	TM	Blood 2	7.6000E-03
Y	Liver 0	Liver 1	4.5286E-02
Y	Liver 0	SI	9.2420E-04
Y	Liver 1	Liver 2	3.8000E-04
Y	Liver 1	Blood 2	1.5200E-03
Y	Liver 2	Blood 2	1.2660E-04
Y	Testes (Ovaries)	Blood 2	3.8000E-04
Y	SI	ULI	6
Y	ULI	LLI	1.8
Y	LLI	Feces	1

Table B: Proposed values for the transfer rates. (partly taken from(3)and(23))

The chelation process, which transfers (atoms of) plutonium between systems y and z, is modeled using a second order kinetics. A term depending on the contents of the corresponding compartments from the x and y system is added to the differential equations of the three systems. Thus the equations for compartment (number i) are given as:

« standard system » « chemical reaction »

$$d/dt\, x[i] = -k_1 * x[1] + k_2 * x[2] + \ldots \; - \; K_R * f(x[i],y[i])$$
$$d/dt\, y[i] = -k_4 * y[1] + k_3 * y[2] + \ldots \; - \; K_R * f(x[i],y[i])$$
$$d/dt\, z[i] = -k_5 * z[1] + k_6 * z[2] + \ldots \; + \; K_R * f(x[i],y[i])$$

The transfer rates k_1,k_2,… describe the biokinetic transport of the atoms/moles (standard system). The kinetics of the chemical reaction is represented by the rate constant K_R. The value of this rate constant may depend on the environment where the reaction takes place (e.g. pH-value, other competing reactions). But in a first step it is assumed, that K_R has the same value in every compartment, which suggests equal environmental conditions in all compartments. The value of K_R must be reasonable "high" because the chelation is assumed to be very fast. Several functions that can be used to connect the systems (e.g.: min(x[1],y[1]), saturation-equation) have been discussed. The group agreed to use a simple proportionality (f(x[1],y[1]) = x[1]*y[1]). The DTPA-molecule itself has no ability to cross cell boundaries, so it is assumed that the chelation only takes place in the Blood1 and ST0 compartments of the current systemic model for plutonium-metabolism(3,13).

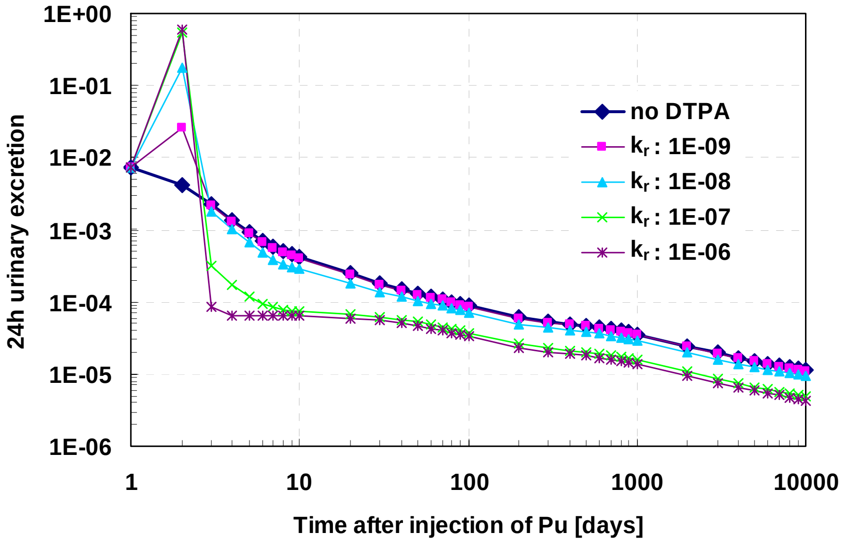
5 CALCULATIONS WITH THE MODEL

Several versions of the model were applied to defined theoretical scenarios and to real contamination cases with DTPA treatment taken from the IDEAS database(6). Generally it is very difficult to fit the proposed model to the data available. Numerical Problems in the solutions have been observed by all participants. Modifications of the model have been suggested and discussed by the members of group. Some of the issues addressed will be presented in this chapter.

5.1 The influence of the K_R constant

The Value of the K_R constant determines the behavior of the proposed model. To study this effect the value was varied from $1 \cdot 10^{-6}$ to $1 \cdot 10^{-9}$ $mol^{-1}d^{-1}$ and the changes in the outputs of the model have been compared. The results for urinary excretion and liver retention are shown in Figure E. The scenario used in this study was an injection of 1 Bq of ^{239}Pu at t=0 followed by a treatment with 1 g of Ca-DTPA at t=1 day after injection of plutonium. As reasonably expected, increasing values of "velocity" parameter K_R determine excretion rates higher than the values calculated in case of no DTPA treatment, owing to a more efficient depletion of the plutonium circulating in the blood. Particularly, the 24h urinary excretion is significantly enhanced. The values of K_R seem to have only minor influence on the duration of the enhancement of the urinary excretion. The enhancement of the 24h fecal excretion after the DTPA treatment can be observed as well, even if at a less significant level than the urinary excretion: in fact, for the lowest values of K_R, the fecal excretion is not significantly affected even if an increase of the urinary excretion can be still observed. The duration of the enhancement of the fecal excretion is not particularly affected. After the initial enhancement at short time after the DTPA treatment, the excretion rates becomes lower than the values calculated in case of no DTPA treatment, particularly for higher values of K_R (after the removal of activity from the circulation due to DTPA action, the excretion at later time is due to the activity stored in the other organs that will slowly clear into the circulation). On the other hand, for particularly low values of K_R, the urinary and fecal excretion rates at few days after the treatment may become soon very close to the values predicted in case of no DTPA treatment. For the other significant organs of plutonium biokinetics (e.g. skeleton and liver), the DTPA treatment always reduces the retention of the activity when high values for the K_R parameter are assumed. Two 'limit' situations can be pointed out:

- For high values of K_R (e.g. $1\cdot10^{-6}$), the 24h urinary and fecal excretion rates at the first day after the treatment are enhanced by about factors 150 and 2. At long time after the treatment the 24h urinary and fecal excretion rates and the retention in the organs of interest (skeleton and liver) are reduced by about the same factor 2.5.
- For low values of K_R (e.g. $1\cdot10^{-9}$), the 24h urinary excretion rate at the first day after the treatment is enhanced by about a factor 6. The 24h fecal excretion is very much less affected (the factor of enhancement is smaller than 1.1). Already at few days after the treatment the 24h urinary and fecal excretion rates are practically not at all affected. The retention in the organs of interest (skeleton and liver) is not significantly affected as well.



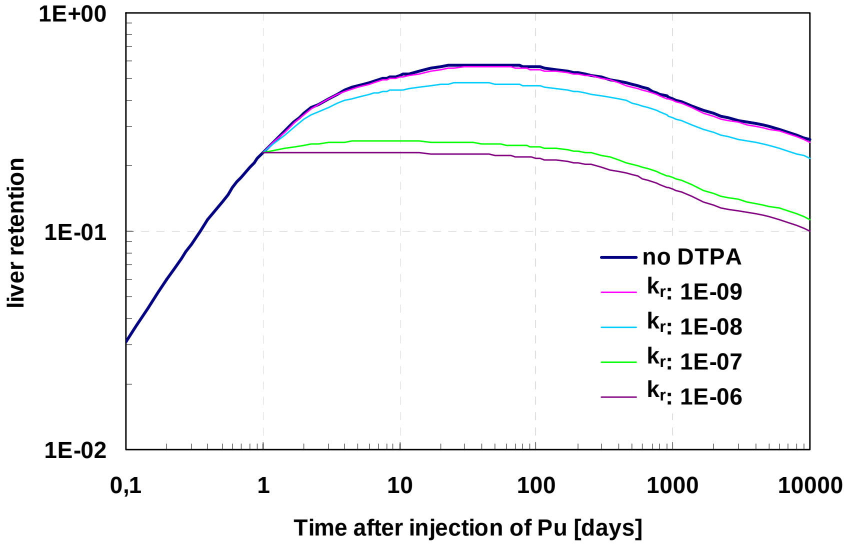


Figure E: Effect of the Value of KR on urinary excretion and liver retention

The values of the observed enhancement of excretion (either urine or feces) and its duration need to be compared to case specific data. This parameter can easily be calculated from measured data. Factors in the range from 2 to 100 have been reported in Literature. Some of the values are:

- 60 to 100(14)
- approx. 80(15)
- about 35(27)
- 30 to 100(28)
- about 41(29)
- 50 to 100(30)
- 25 to 100(31)
- 2 to 20(18)
- about 50(20)
- about 40(10)

The enhanced excretion in urine has been reported to last over some (up to 100) days by several authors(14). Other authors present data, in which only the urinary excretion on the day after treatment is said to be influenced significantly(10).

5.2 Model properties: Theoretical Scenarios

The group looked at four different theoretical therapies to study the properties of the proposed model and to do some quality assurance for their different implementations. The scenario assumes an injection of 1 Bq of ^{238}Pu at t=0. Several possible treatment options have been modeled and compared :

case (a) no DTPA
case (b) 1 g of DTPA at t=1h
case (c) 1 g of DTPA at t=10d
case (d) 1 g of DTPA at t=1, 10 and 15 d
case (e) DTPA at t=10d (different dosage 0,5g vs. 1g vs. 2g of DTPA)

Immediately after the therapy the DTPA molecules are in massive excess compared to the total amount of plutonium available. Converting the injected activity and the applied dosage of DTPA in the unit of moles shows a factor of up to $3.0 \cdot 10^{11}$ for the ratio DTPA:Pu immediately after treatment. As shown in Figure F, after the treatment the overall part of plutonium excreted in urine is in the form of Pu-DTPA-complex, as expected. Nearly all of the available plutonium is chelated, thus the mathematical representation of the chelation process shows only a minor influence.

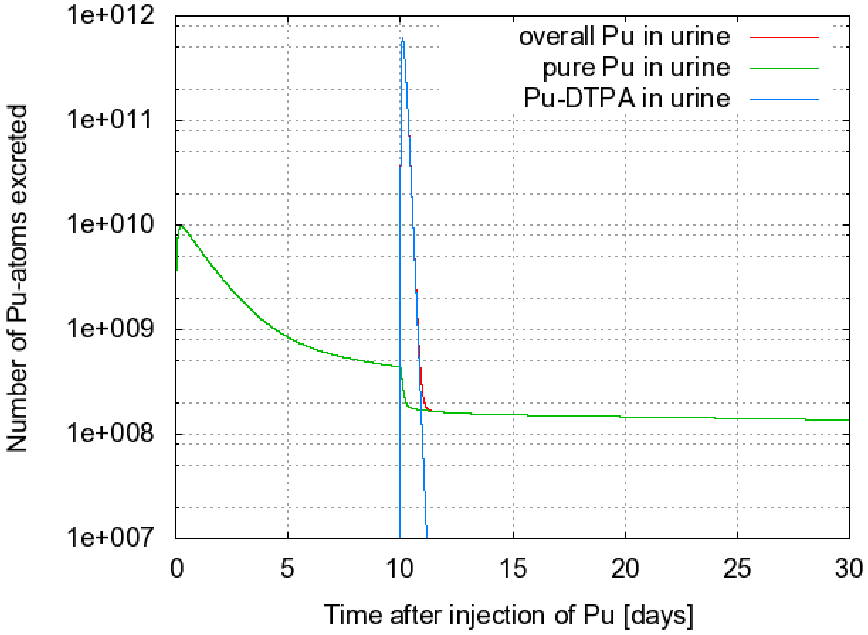


Figure F: Reference Scenario, treatment 10d after Injection intake, distribution of plutonium atoms excreted among the compartmental systems y and z.

Different dosages show no significant effect in the model (see Fig. G) because the order of magnitude of the DTPA:Pu ratio does not change significantly.

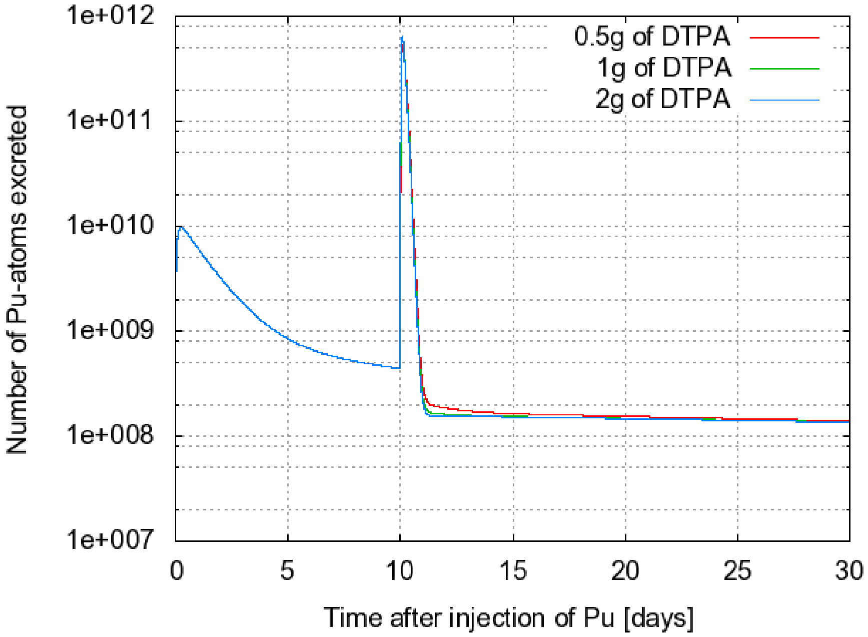


Figure G: Reference Scenario, treatment 10d after Injection intake, effect of different dosages of DTPA on the urinary excretion of plutonium

The effects of the different therapies on the whole body retention of plutonium is shown in Figure H. As was expected the model shows an early therapy to be more effective than a delayed therapy. In this scenario, the percentage of plutonium decorporated over 100 days after an intake is about 16% of the intake for a treatment performed on day 10 (compared to the 3% for the untreated subject). One has to keep in mind that these are only theoretical values based on the model assumptions and that these can not be compared to existing data. But the model shows the effects that were expected and the structure showed/seemed to be suitable to assess real case data.

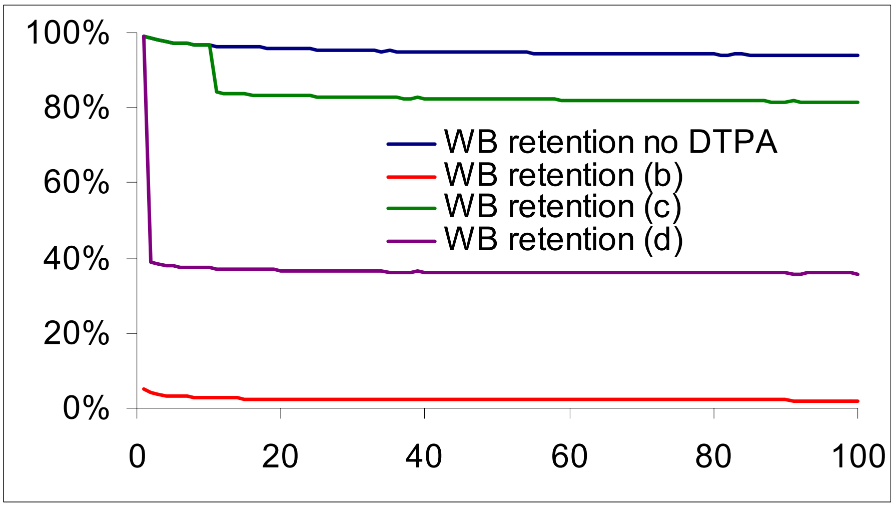


Figure H: Reference Scenario, effect of different times of DTPA therapy on the whole body (WB) retention of plutonium.

5.3 Model Application: Case Studies

For further studies on the model, four real contamination cases treated with DTPA have been chosen from the IDEAS database(6). Two wound and two inhalation intake cases were selected because of the extensive follow-up by both *in vivo* and *in vitro* measurement. However, the fitting of the model is very sensitive to the quality of the bioassay data and to the assumptions about the uptake.

Case 208 : Pu + Am wound contamination

This case was presented by Piechowski(32). It took place in an analytical laboratory for radiochemical characterization of actinides. A worker used a screwdriver to tie a collar on a tube. The screwdriver slipped and wounded the index of the left hand at the level of the 3rd phalange. The worker was sent to the medical centre. Contamination of wound was established and perfusion with DTPA was set up one hour after the accident started (500 mg in 1 hour). Careful cutaneous decontamination was performed; the wound was washed with a DTPA solution. The isotopic composition was alpha activity $^{239/240}$Pu = 26%, ^{238}Pu = 60%, ^{241}Am= 14%; beta/alpha activity ratio = 22.

A sum of four exponentials terms was fitted to the wound retention data and extrapolated back to day 2 in order to describe the uptake of Pu from the wound into the blood. A good fit to the wound retention was achieved. Still the model is not able to properly describe the observed excretion enhancement (Fig. I and J). The observed Pu urinary excretion is often larger than the amount assumed to be cleared from the wound and available for chelation. There is therefore some error in the uptake model derived from the *in vivo* measurement of the wound.

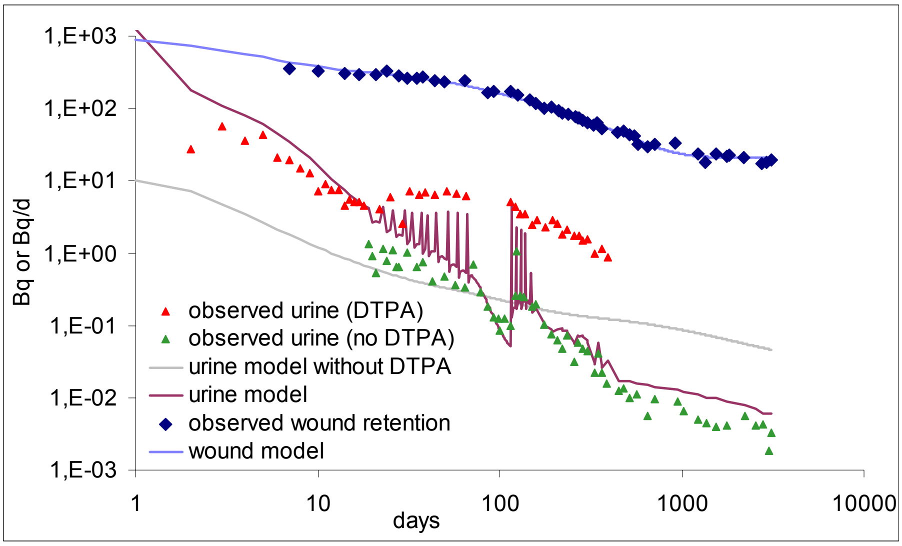


Figure I: Wound retention and daily urinary excretion in case 208, measured data and model predictions. Observed urine (DTPA / no DTPA), a DTPA/ no DTPA injection was performed at the beginning of the 24h urine sampling period.

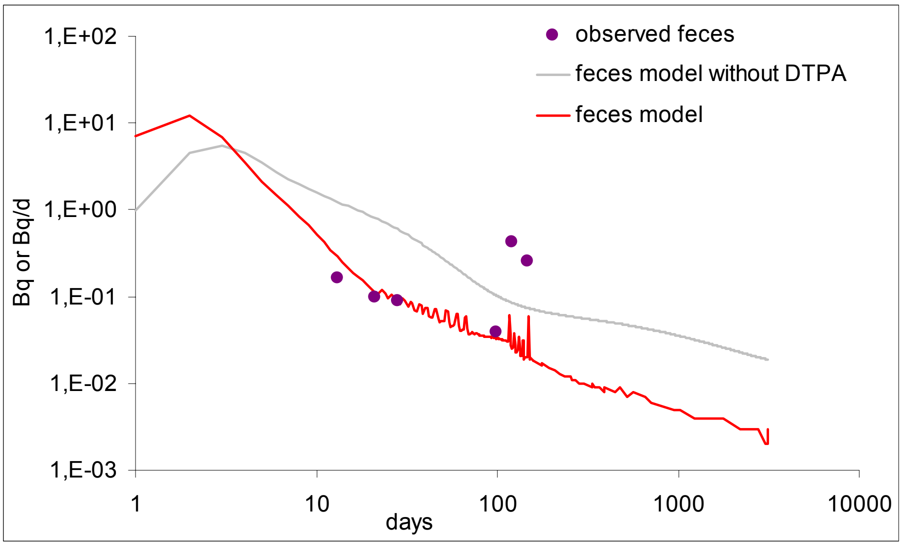


Figure J: Daily fecal excretion in case 208, measured data and model predictions.

The time lapse between the intake of Pu and the first DTPA treatment (>1d) is important because the model shows a large dependency on the duration and time of treatment (12h vs. 6h vs. 1h after incorporation) and on the delay before urine sampling (in hours). Although the comparison of the model prediction with the observed excretion data tends to suggest that the model underestimates the duration of effect the DTPA treatment, presumably ignoring some pool of Pu available for chelation, the uncertainty on the Pu uptake rate from the wound and on the precise delay between DTPA injection and urine sampling makes it hard to draw definitive conclusions.

Case 123 : Wound Contamination by Pu-239

This case was reported by Jeanmaire(33). A hand wound was caused by a broken glass and gloves were contaminated with hexavalent ^{239}Pu. A surface decontamination reduced the contamination from about 2.22 MBq to about 555 kBq. A surgical excision reduced it to about 74 kBq. Hand, blood, urine, feces and bone activity measurements were performed and DTPA was injected.

As for case 208, the uptake rate from wound into blood is described by a sum of four exponentials fitted to the wound retention data. But in this case no early wound data is available, which makes the back extrapolation less reliable. A large effect of DTPA on urinary excretion, enhanced by about 2 orders of magnitude, was observed for several days. This could not be described by the model assuming that only the amount of Pu in circulation was available to chelation (fig. K and M). The fast chelation process dominates the model outputs and only short durations of excretion enhancement are predicted.

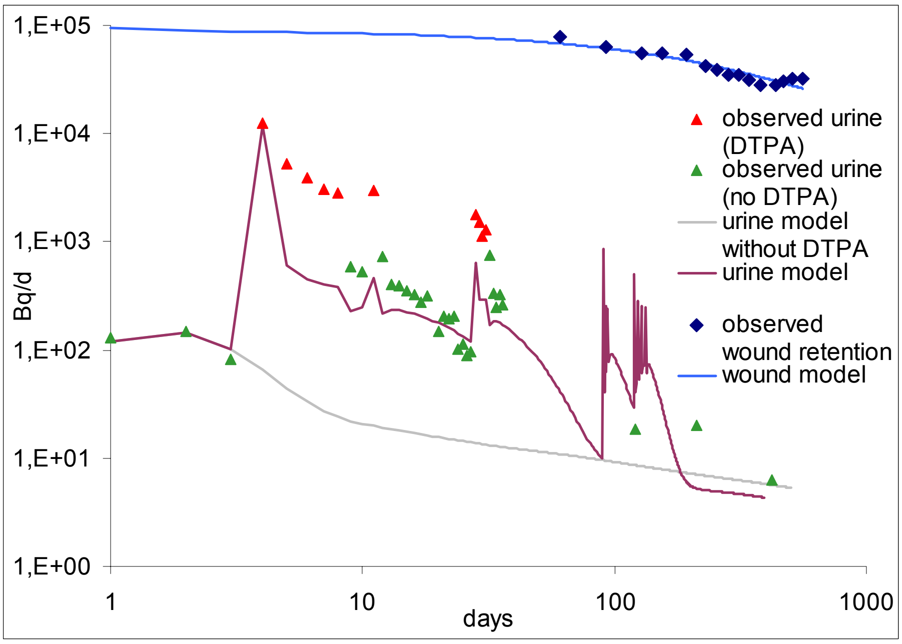


Figure K: Wound retention and daily urinary excretion in case 123, measured data and model predictions. Observed urine (DTPA / no DTPA), a DTPA/ no DTPA injection was performed at the beginning of the 24h urine sampling period.

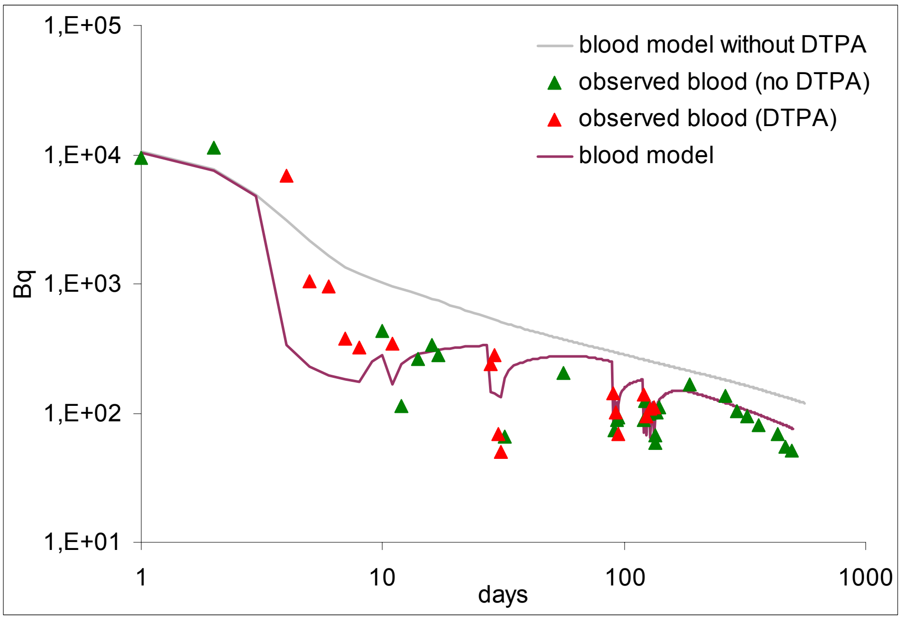


Figure L: Blood retention in case 123, measured data and model predictions. Observed blood (DTPA / no DTPA), a DTPA/ no DTPA injection was performed just before blood sampling.

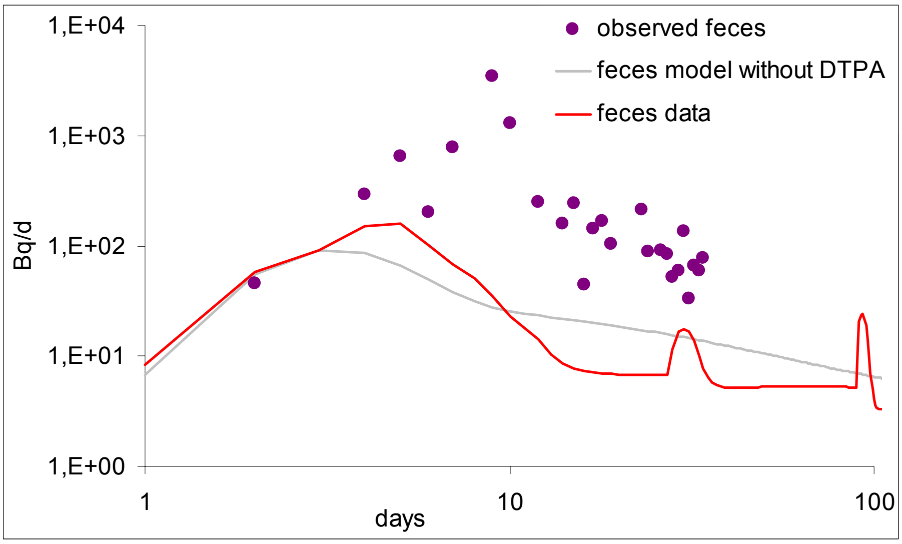


Figure M: Daily fecal excretion in case 123, measured data and model predictions.

Cases 47 and 240 : Inhalation of Pu + Am

These two cases of occupational inhalation intake treated with DTPA injection were also selected due to the number of available data but the application of the Pu-DTPA model to them could not be tested during the course of the CONRAD project. This application will be included in future work.

6 CONCLUSION AND PERSPECTIVE

For the theoretical scenarios investigated the model showed the expected behaviour, but no good fit to real case data could be achieved by the model structure proposed so far. The current model and its modifications have some interesting features but are not realistic yet. New modifications including pathways for DTPA and chelation in liver compartments are studied at the moment. Nevertheless some things have been learned by the investigations so far:

- The problem turned out to be more complicated than expected.
- The complexation process dominates excretion.
- The fitting of the model to published data is most dependant on the accuracy of the activity measurements

One important aspect in the decorporation is the excess of DTPA molecules compared to atoms of plutonium in the blood. The ratio of moles of DTPA to moles of plutonium is in the order of magnitude of 10^{11}. The chelation process (as modeled in our approach) is much faster than any other kinetic process involved. The ratio of the chelation constant K_R used in the model to the constants of other pathways for clearance of plutonium from blood is larger than 10^4. Nearly all of the plutonium present in circulation is thus immediately bound to DTPA. As a consequence the exact form of the mathematical modeling for the complexation process in our model is not as important as was assumed in the beginning, but one has to be careful in implementing the model because the large difference in orders of magnitude may introduce numerical problems. The interpretation and the coupling of the new physiological model of “pure” DTPA to the plutonium biokinetics (like for example the identification of interstitium as the location of complexation) is a point currently investigated by the group. This could replace the rather simple approximation in the CONRAD approach and be a further step toward a more physiologically realistic model of decorporation therapy.

Available datasets show additional excretions that are larger than the amount of plutonium assumed to be available in circulation. The amount and form of the plutonium available for chelation still needs to be characterized.. Skeleton and liver retentions may be affected by DTPA therapy even without considering a direct effect in the organs due to the disturbed flow from blood to the organs. But a direct effect on plutonium in liver or bone may also be assumed. Still, a strong support of bioassay data is needed to clarify this issue. We therefore need detailed studies of human cases with well known uptake and experimental data about DTPA and Pu-DTPA kinetics, preferably from large mammals. The quality of the bioassay data is an important point for the modeling and the assessment of cases. A monitoring procedure that could distinguish between Pu-Transferrin and Pu-DTPA complexes in plasma or urine could help to understand this sub-problem of decorporation therapy.

Chemical speciation is neglected in the modeling yet. But this may be an important factor to consider in future studies. Unfortunately only minor information about chemical speciation is available in human contamination case data and in the large amount of literature describing animal experiments. A deeper understanding of the biochemical and physiological processes concerning metabolism of plutonium and DTPA in the blood, organs and especially the extracellular fluids (the interstitium) is needed. Plutonium is known to bind on the Transferin proteins in blood plasma. The (in-vivo) removal of plutonium from the Pu-Transferin-complexes by DTPA needs to be studied in more detail. Experiments to describe/quantify the fraction of the decorporable form of plutonium and its location inside the body must be carried out. A better understanding of the behavior and the properties of the M-DTPA (M=Ca, Zn, Pu or other metals) in-vivo is needed for modeling decorporation therapy. The effective duration of the decorporation process surely depends on these properties. Especially the question of the in-vivo stability needs to be answered for the compounds and complexes involved. The dependency of efficacy on Ca/Zn-DTPA dosage, route of administration and form of administrated DTPA can only be understood and modeled with this biochemical/physiological knowledge. In rat experiments an effect of dosage was reported by Phan(34).

Recently, experimental studies at CEA have been specifically developed in rats to warrant different hypotheses for modeling decorporation of plutonium by DTPA. These experiments show that after inhalation of PuO_2, DTPA decorporation involves the fraction of dissolved actinides which is retained in the lungs rather than systemic retention compartments(35). After systemic contamination, at the standard DTPA dosage of 30 $\mu mol.kg^{-1}$, Pu-Transferrin complexes are not the main source of the decorporated plutonium. The source of decorporated actinides appears to be plutonium chemical forms encountered just before deposition in the retention organs rather than the deposited plutonium. Moreover, pilot experiments indicate that in vivo stability of Pu-DTPA complexes depends on the ratio of DTPA versus Pu-DTPA(36).

These new results allow us to identify the main problems to solve in order to provide a more realistic modeling approach:

- Which is the relative contribution of the site of contamination (e.g. lung or wound) and of the systemic retention compartments to the amount of decorporated Pu?
- Which is the half-life of the Pu-DTPA complexe and its kinetics of formation from Pu-Transferrin?
- How does the in-vivo behaviour of plutonium and DTPA depend on the chemical speciation?

We slowly approached but still are far away from understanding the mechanism of decorporation therapy. The CONRAD approach shows to be a promising way towards a generic model of decorporation therapy. Many issues have been investigated and discussed by the group. It was very advantageous that the members of the group had different scientific backgrounds (e.g. biologists, physicians, physicists, toxicologists) which could supply their different points of view and experiences to the discussion. But for most questions discussed the group discovered even more open questions instead of direct answers to the one originally under investigation. More research and effort in future is needed in understanding, describing/modeling and optimizing decorporation therapy by DTPA. Especially a set of carefully planned animal experiments is needed. The group wishes to continue this important work beyond the framework of the CONRAD project.

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3.3.- CONRAD TASK 5.3: NEW DEVELOPMENTS ON MONTE CARLO APPLICATIONS TO IN-VIVO ASSESSMENT OF INTAKES

Coordinator: Didier Franck (IRSN, France)

DELIVERABLE 5.3 - Final Report, FEBRUARY 2008

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CONRAD TASK 5.3: NEW DEVELOPMENTS ON MONTE CARLO APPLICATIONS TO IN-VIVO ASSESSMENT OF INTAKES

ABSTRACT

The new developments in the use of voxel phantoms and Monte Carlo (MC) applications for assessment of intakes from in-vivo measurements have been evaluated within CONRAD, as a joint WP5-WP4 collaboration. The “Intercomparison on Monte Carlo modelling for in vivo measurements of Americium in a knee phantom”(12)(13)(14) was organized by CIEMAT and IRSN, and the results were presented at the Workshop “Uncertainty Assessment in Computational Dosimetry. A comparison of approaches” organised by ENEA, in Bologna, in October 2008.

A voxel phantom was generated at CIEMAT from the CT-images of a real knee phantom used for calibration purposes. A counting geometry using 2 LE Ge detectors was proposed. The exercise was distributed by e-mail to the laboratories. Counting efficiency results obtained by Monte Carlo simulations by the 13 participants of the Intercomparison were very close to the experimental efficiency value for ^{241}Am (using photopeak of 59.5 keV) obtained through the measurement of the active Spitz calibration knee-phantom at the CIEMAT Whole Body Counting facility.

The objective of the intercomparison was to confirm MC methods and voxel phantoms as valuable tools for the calculation of in-vivo calibration factors for whole body counting systems, to be applied for the assessment of intakes and internal doses. The comparison of MC codes and the evaluation of the capability of laboratories to deal with such type of exercises were also analysed.

In this framework a joint action has been established with DOE (Department of Energy, USA) to collaborate for an in-vivo monitoring and MC modelling exercise for the determination of the ^{241}Am deposited in the USTUR (United States Transuranium and Uranium Registry) knee phantom, containing real contaminated bone from a real internal contamination.

A protocol has been proposed, and a small group of selected laboratories from Europe (CIEMAT, IRSN, Helmholtz Zentrum München) and America (HML-Canada, PNL-USA) participated in the exercise. The studies to focus on are: (1) the efficiency pattern along the leg phantom (experimental and computational) and (2) the influence of Americium distribution in the bone material (volume or surface). This action is not finished yet and the results will be published in the future.

CONRAD TASK 5.3: NEW DEVELOPMENTS ON MONTE CARLO APPLICATIONS TO IN-VIVO ASSESSMENT OF INTAKES

CONTENTS

1 Introduction

2. The International comparison of Monte Carlo modelling for in vivo measurements of Americium in a knee voxel phantom

2.1 Material and methods
  2.1.1 General Criteria for the Intercomparison
  2.1.2 Knee Voxel Phantom
  2.1.3 Detail of the proposed tasks

2.2 Results
  2.2.1 Analysis of the results of task a: calibration source simulation
  2.2.2 Analysis of the results of task b: simulation of knee phantom measurement

3. The International comparison of measurements and Monte Carlo modelling for Americium in the USTUR leg phantom

3.1 Motivations
3.2 Objectives
3.3 Participants
3.4 Current status of the action

4. Conclusion and Prospects

5. References

1 INTRODUCTION

The radiation protection of atomic industry personnel handling radionuclides, Fission and Activation Products (FAP), actinides, etc., inevitably involves radiation monitoring and internal exposure control. The specialized techniques of individual monitoring used at atomic enterprises include the application of dynamic air concentration assessment in the working room air, sampling of human excreta and whole body counting spectrometry. This later technique, which uses high-purity germanium detectors, is valued by numerous advantages. Among such advantages are the possibilities of fast assessment of incorporated activity and high counting efficiency within wide range of energy for gamma emitters leading to wide use in medical laboratories dealing with workers survey.

On the other hand, whole body counting has several disadvantages as well. The most crucial disadvantage is the need for interpretation of the measurement, to convert the number of pulses in spectrometry channels into retained activity. This process, called calibration is based on the use of plastic phantoms (mannequins) containing a well known activity. However, the standard reference phantoms do not take into account the individual anatomy of a given subject, the specific size, shape, weight of his (her) organs as well as their position in the body. To make the things worse, the most radiotoxic incorporated radionuclides (such as ^{239}Pu and ^{241}Am) emit low-energy (13-60 keV) -rays. As a result, determination of whole body (or organ) counting calibration coefficients is hampered due to intensive absorption and scattering of radiation in the patient’s body (organs).

To circumvent these obstacles, one could use mathematical simulation (particularly Monte Carlo Method (MCM) as almost the only valid calculation method for such a purpose) rather than measurement of reference phantoms. Two opposite approaches are possible using the MCM: either to use mathematical phantom described with mathematical equations (or geometry using the combination of solid: cylinders, spheres…) or to use the voxel (small volume elements, pixels in 3D) approach. These two opposite approaches both have several advantages and disadvantages. The advantage of the first approach is mostly the simplicity of anatomy description that accelerates the calculations. On the contrary, when the shape of the phantom or when treating human subject, the latter approach, based on voxel phantoms, is preferred since description of the geometry can be more complex. Moreover, the voxel approach allows describing precisely the individual patient anatomy, but requires significant resources of computer memory and run-time for transport calculations [1].

State of the art

From these observations, an innovative approach has been developed at IRSN, for the creation and application of voxel phantoms associated to Monte-Carlo calculation (MCNP) for calibration of whole body counting systems dedicated to the in vivo measurement. The new method is based on a Graphical User Interface called "OEDIPE" which allows simulating whole measurement process using all measurement parameters, the final goal being to approach a numerical calibration of the facilities. Different application, have demonstrated the possibility of such a calibration using the Monte Carlo technique in previous research programs (OMINEX [2], IDEA [3]) such as the valuation of uncertainties in the assessment of lung activity and Virtual calibration of a low-energy in vivo counting system. However these works have also emphasized the actual limits of this new approach. If it allows a better representation of phantom especially when using voxel phantoms and the calibration for all type of radionuclides and energies, this technique remains rather complex to be used in routine laboratories (knowledge of Monte Carlo calculation) and time consuming and the use of quite powered computers is well recommended. Moreover, because of the quite recent application in this field, optimization of Monte Carlo parameters (tallies, resolution of the voxellised phantom, etc, …) have to be studied and optimized.

Objectives proposed

In order to analyse such variations when different approaches are applied to simulate a real experimental case, two “Intercomparison on MC modelling for in vivo measurement of Americium in a knee phantom” are being organized.

The first intercomparison is a joint initiative of work packages 4 (WP4: computational dosimetry) and 5 (WP5: internal dosimetry) of the EU Coordination Action CONRAD (Coordinated Network for Radiation Dosimetry), partly supported by the Sixth Framework Programme (Contract no. FP6-12684) [4].

The second one is an initiative of the work package 5 that has been decided in October 2006 during the International Workshop on Internal Dosimetry of Radionuclides (ID2006) held in Montpellier. This task was not planned in the original program of the WP5, but due to the interest of participants for this action, it was added as a secondary objective of subgroup 5.3. This action is an intercomparison exercise that considers both, in-vivo measurements and Monte Carlo modelling of Americium in the DOE Leg phantom. This phantom contains a real bone contaminated with ^{241}Am. This task is not achieved yet, but details on the objectives, participants, and current status are given in ***section 3***.

2 THE INTERNATIONAL COMPARISON OF MONTE CARLO MODELLING FOR IN VIVO MEASUREMENTS OF AMERICIUM IN A KNEE VOXEL PHANTOM DUCTION

This chapter summarizes the main points concerning the “International comparison on MC modelling for in-vivo measurement of Americium in a knee phantom” organized within the EU Coordination Action. The analysis has been based on fifteen numerical simulations of a real in-vivo measurement of 241Am in a knee phantom, provided by thirteen laboratories of ten countries around the world that participated in this initiative (Table 1). The details of the organisation and the proposed exercises have been published in ref. [6] and [7].

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Table 1. Participants to the intercomparison exercise.

2.1.- Materiel and methods

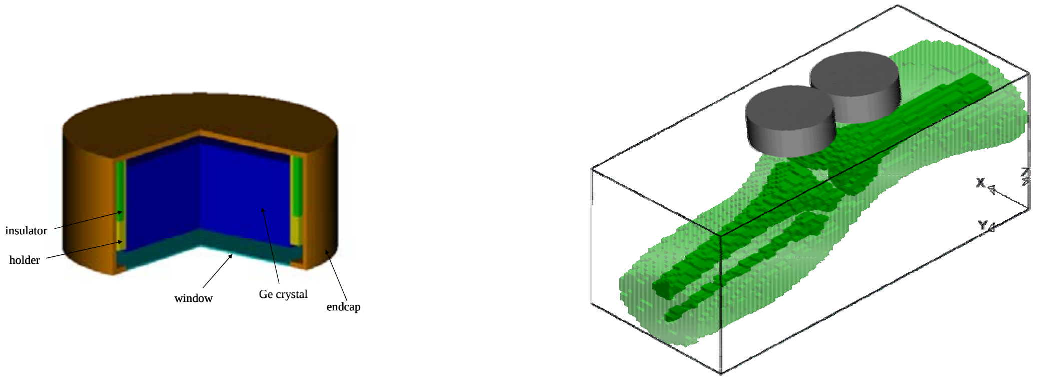
2.1.1.- General Criteria for the Intercomparison

The main goal of the intercomparison exercise was the training of participants in the Monte Carlo simulation of *in vivo* measurements of bone-seekers radionuclides using Germanium detectors. For this purpose the proposed exercise focused on measurements of ^{241}Am in a knee phantom, being the knee a usual counting geometry for bone seekers radionuclides since it represents an important content and “easy to measure” bone mass. The different tasks of the exercise represent the successive steps that should be followed during a real case measurement.

The detection system consisting of two Canberra Low Energy germanium detectors (LEGe) had to be simulated according to the technical specifications provided by the manufacturer. In addition, a knee voxel phantom representing a human left knee had been built based on a computerized axial tomography of the Spitz anthropometric knee phantom. The participants have been asked to deal with the simulation of in vivo monitoring of ^{241}Am in the knee using their own Monte Carlo codes together with the knee voxel phantom and detectors mentioned above. The comparison has been mainly focused on two specific aspects as shown in ***Figure 1***:

a. Simulation of a single LEGe detector for a point ^{241}Am source in air.

b. Calculation of the energy distribution of pulses and peak detection efficiency in a two LE Ge detectors system due to a homogeneous distribution of ^{241}Am in bone.



Task a: Energy distribution of pulses and peak detection efficiency in a single LE Ge detector, for a point ^{241}Am source.

Task b: Energy distribution of pulses and peak detection efficiency in a pair of LE Ge detectors, due to a homogeneous distribution of ^{241}Am in bone.

Figure 1. Intercomparison on MC modelling for in vivo measurement of Am in a knee phantom

The detection system to be simulated consisted of two Canberra Low Energy germanium detectors (LEGe) operating at the CIEMAT Whole Body Counter Laboratory. Details about materials, densities and sizes of the detector are shown in ***Figure 2***. A thin dead layer located at the front of the Ge crystal (the side closer to the carbon window) should be considered for the simulations (see the detail of the proposed tasks in section 3). The energy calibration and the resolution of the detector (FWHM of photopeaks as a function of energy) have also been provided to the participants[7].

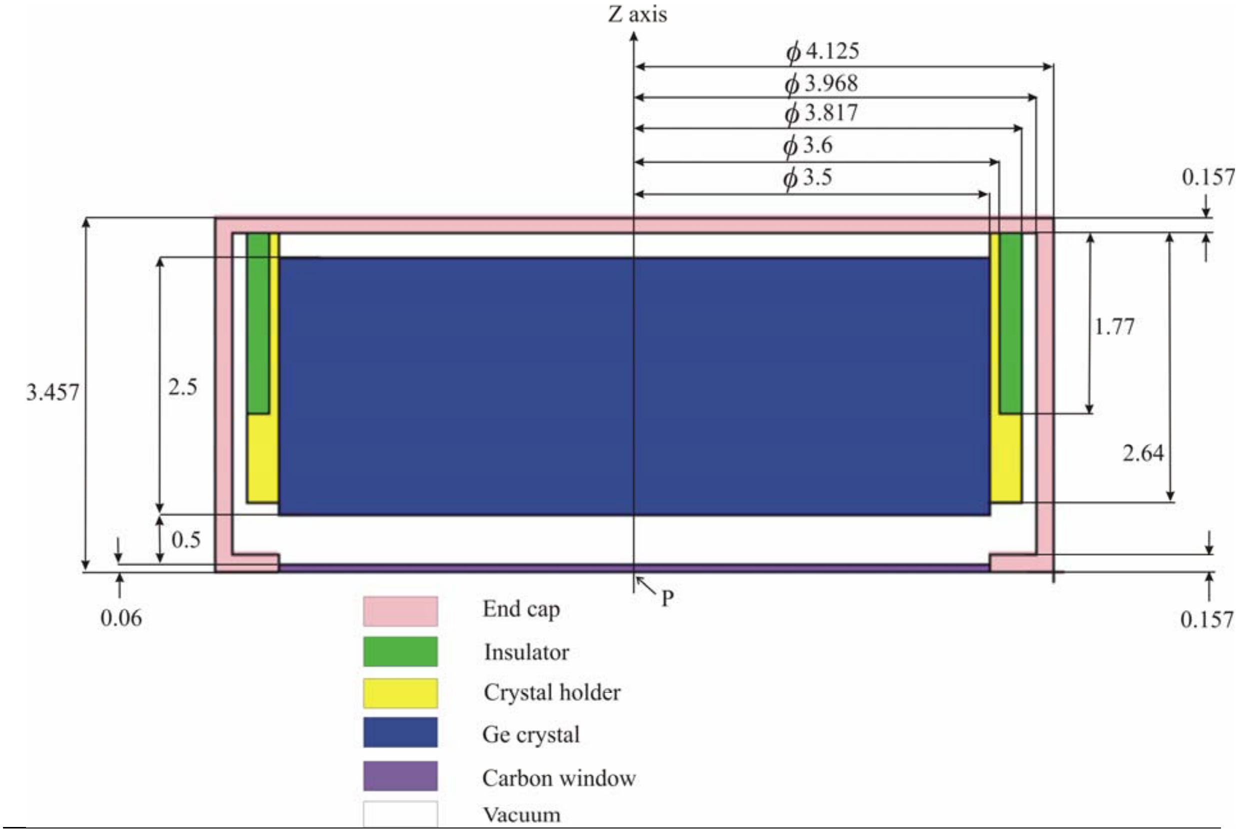


Figure 2. Cut view of the LE Ge detector with dimensions (in cm) and materials. The detector has cylindrical symmetry around the Z axis. Point P (on the external surface of the carbon window) is directed towards the source.

2.1.2.- Knee Voxel Phantom

A knee voxel phantom representing a human left knee has been built based on a computerised axial tomography (CAT) of the Spitz anthropometric knee phantom (***Figure 3***). The Spitz phantom was fabricated by University of Cincinnati for in vivo calibration purposes. The original images stack (rows: 512, columns: 512, slice thickness: 5 mm, pixel spacing: 0.53125 mm, colour depth: 16 bit gray) has been processed to distinguish both air and bones from muscle tissue. Then, pixel spacing has been re-scaled to 2 mm resulting in a voxel phantom with 3 materials and voxel sizes: □x = 2mm, □y= 5mm, □z = 2mm (***Figure 4***). The materials composition have been specified according to the ICRU specifications [11], namely “Dry air”, “Muscle tissue” and “Trabecular Bone” were selected in agreement with the specification of the manufacturer [5]

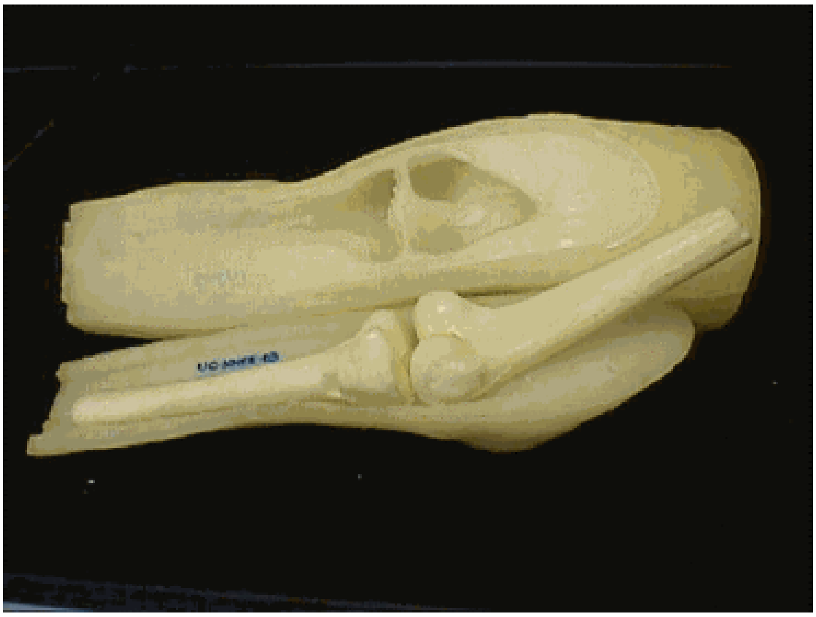


Figure 3: Spitz anthromorphic knee phantom [5]

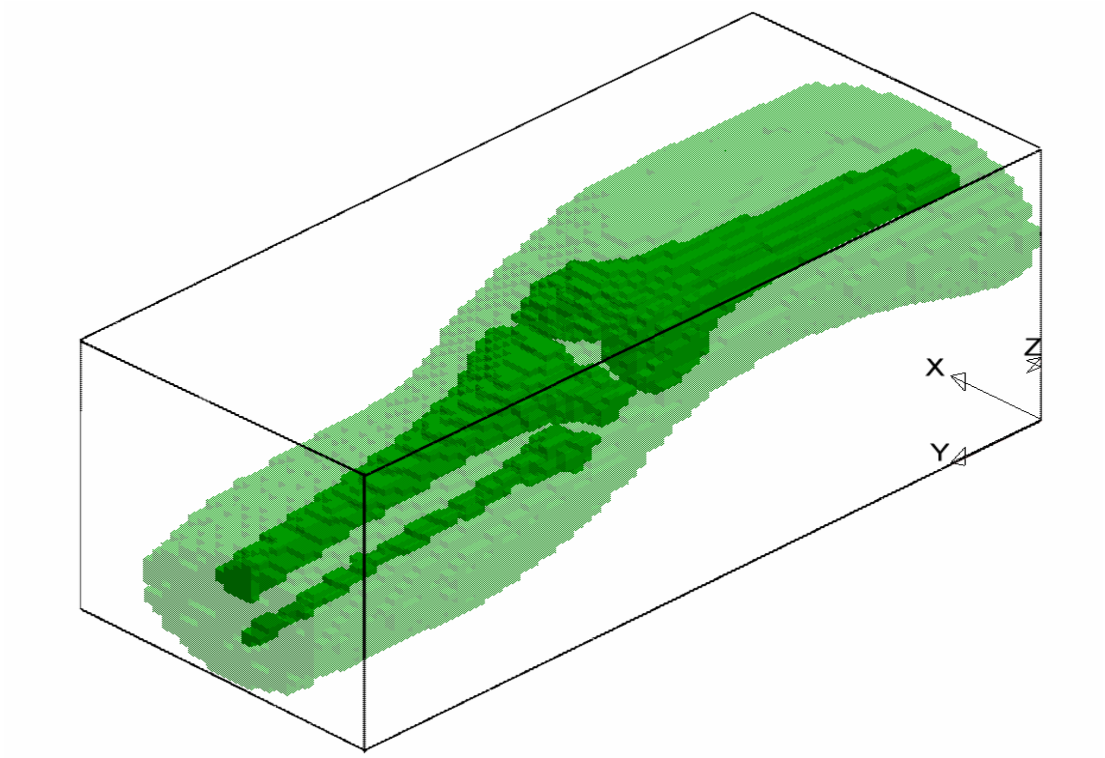


Figure 4: Schematic view of the knee voxel phantom and the reference coordinate system

2.1.3.- Detail of the proposed tasks

Task a : Efficiency calibration and pulse height spectrum in a single LE Ge detector for a point ^{241}Am source.

Previously obtained results [8] demonstrated that significant differences in the simulated pulse height spectra can be expected just depending on the MC code (i.e. the transport models and the implicit approximations) used for the simulations.

To simplify the geometry, the measurement of a ^{241}Am point source at a distance d = 5 cm from the centre of the carbon window of the detector (point P in Figure 1) along its main axis has been considered. Then, it has been asked to simulate: (i) Pulse height distribution in the active Ge region for the energy binning corresponding to the multichannel analyzer actually employed in the experimental measurements; and (ii) peak efficiency at 59.5 keV.

Task b: Efficiency calibration and pulse height spectrum in a two LE Ge detectors system for a knee phantom with an homogeneous distribution of ^{241}Am in bone.

Once eventual discrepancies among the solutions provided by the participants may have been identified in the simulation of either the detector or the knee phantom, the actual in vivo measurement should be simulated and compared with the experimental result. In order to avoid undesired difficulties arising from a too complex counting geometry that may require the specification of angles in space, a simple arrangement with two vertical detectors located on the knee (along the Z axis, according to the reference system adopted for the voxel phantom) has been chosen (see Figure 1). As for the case of a point source and a single detector, pulse height distribution in the active Ge region of the detection system and peak efficiency at 59.5 keV are going to be both measured and simulated.

2.2.- Results

Complete results have been presented and discussed in the Workshop on Uncertainty Assessment on Computational Dosimetry (Bologna, Italy, October 8-10, 2007). They have been published in ref. [10]

Special attention has been paid to the critical analysis of similarities and discrepancies, both among the different numerical solutions and comparing these with the experimental results (for task 1 and 3), arising from the different MC codes and models used to simulate photon/electron transport and interaction processes in the range 10-60 keV. It should be noted that most participants (8/13) use MC codes from the MCNP family

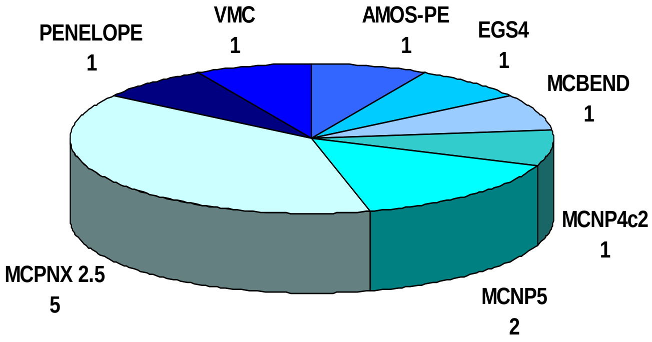


Figure 5: Monte Carlo codes used by participants

2.2.1.- Analysis of the results of task a: calibration source simulation

The analysis shows that most of the solutions are in very good agreement between each others and with the experimental measurement for the simulation of the photopeak at 59.5 keV.

However, serious discrepancies have been found between simulated and measured data, in the region below the 59.5 keV photopeak. These discrepancies are (i) the shape of the Compton profile and (ii) the amplitude of photopeaks due to the low energy gamma and X-rays of ^{241}Am. Concerning the Compton profile, the discrepancies between simulations and measurements, have been resolved taking into account a complete description of the calibration source. Instead of modelling an ideal point source the real calibration source with its plastic cover and a non-zero surface has been considered. As a result a spectacular improvement of the Compton profile modelling is obtained, as it can be shown in ***Figure 6***.

The modelling of low energy photopeaks is also improved when a realistic description of the calibration source is used, but the relative improvement is not so good than for the Compton profile. Some reasonable explanation can be advanced to explain the resulting discrepancies; these points have been discussed by participants of the Bologna workshop:

- Modelling of the plan where the source is lying enable to take into account the scattered part of the radiation
- The physic models and cross-sections at low energy strongly depend on material composition; small deviation from real material composition of phantom and detectors can induce large differences in the simulated quantities.
- The dead layer thickness of the detector has been adjusted; at low energy one can question the influence of this adjustment.
- The detailed structure of X-rays peaks is not known in detailed, even when one considers up-to-date nuclear data libraries.
- Other aspects specifically related with photon and electron transport at the energy range of 10-30 keV have been also considered in the final analysis. Information is available in the website: http://www.eurados.org/ (***Figure 7***).

As a conclusion of this task it must be emphasized that, despite some discrepancies at low energy, the main photopeak is well simulated. This is the crucial point since only this peak is used for real case measurements.

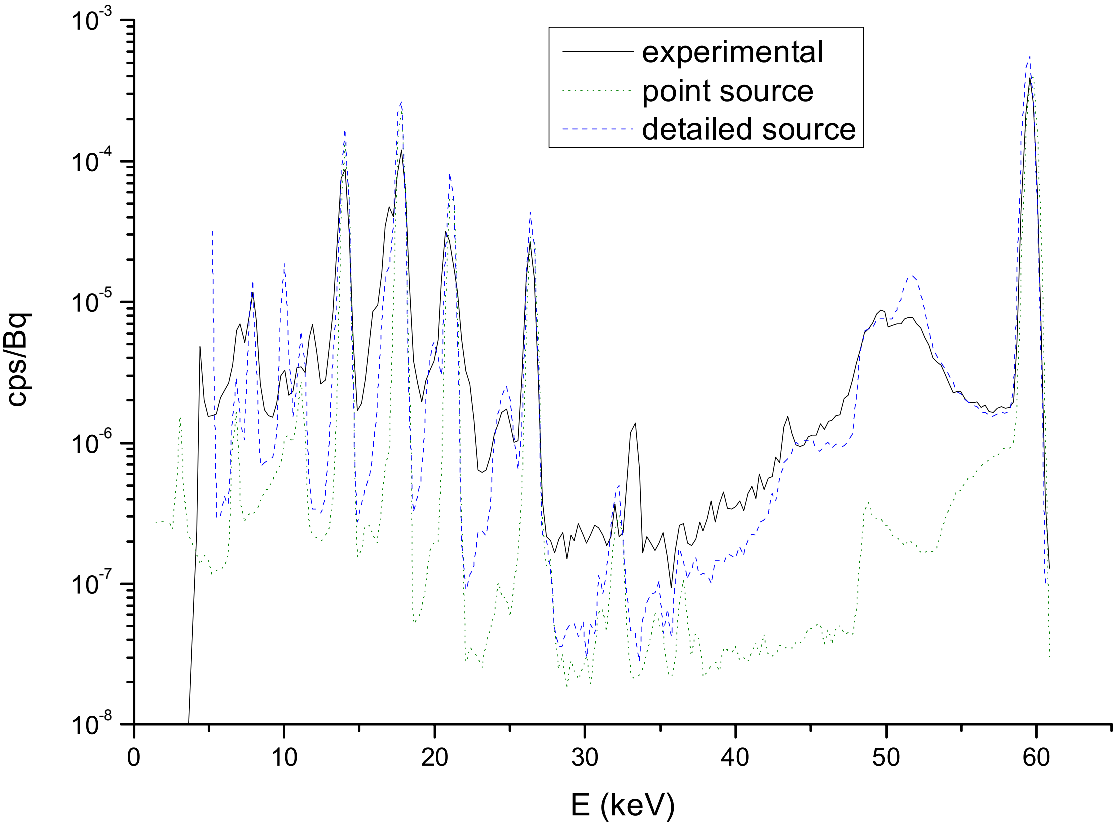
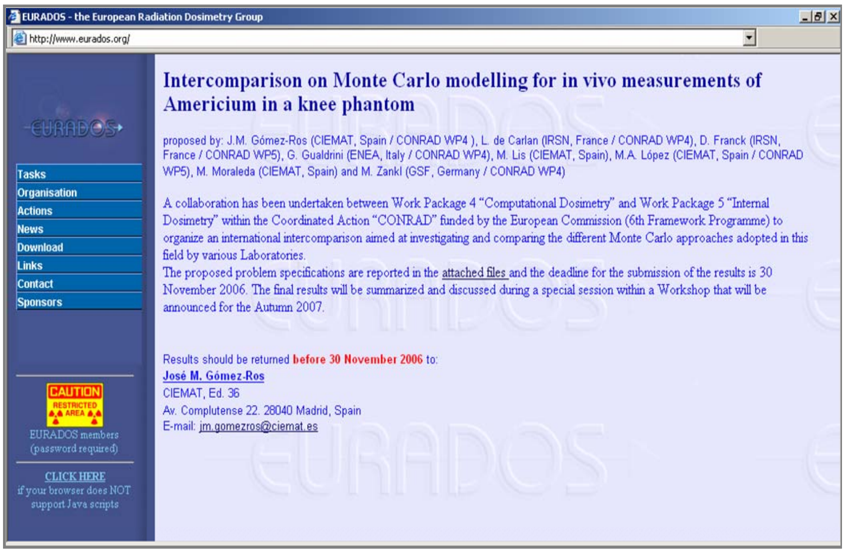


Figure 6: Comparison of the measured pulse-height spectrum for a reference source (Task a) with the simulated curves obtained assuming both a mathematical point source and a detailed modelled source.



Intercomparison on Monte Carlo modelling for in vivo measurements of Americium in a knee phantom

proposed by: J.M. Gómez-Ros (CIEMAT, Spain / CONRAD WP4), L. de Carlan (IRSN, France / CONRAD WP4), D. Franck (IRSN, France / CONRAD WP5), G. Gualdrini (ENEA, Italy / CONRAD WP4), M. Lis (CIEMAT, Spain), M.A. López (CIEMAT, Spain / CONRAD WP5), M. Moraleda (CIEMAT, Spain) and M. Zankl (GSF, Germany / CONRAD WP4)

A collaboration has been undertaken between Work Package 4 "Computational Dosimetry" and Work Package 5 "Internal Dosimetry" within the Coordinated Action "CONRAD" funded by the European Commission (6th Framework Programme) to organize an international intercomparison aimed at investigating and comparing the different Monte Carlo approaches adopted in this field by various Laboratories.
The proposed problem specifications are reported in the attached files and the deadline for the submission of the results is 30 November 2006. The final results will be summarized and discussed during a special session within a Workshop that will be announced for the Autumn 2007.

Results should be returned **before 30 November 2006** to:
José M. Gómez-Ros
CIEMAT, Ed. 36
Av. Complutense 22. 28040 Madrid, Spain
E-mail: jm.gomezros@ciemat.es

Figure 7: EURADOS Web site

2.2.2.- Analysis of the results of task b: simulation of knee phantom measurement

Quite surprisingly, the general agreement between simulated and measured spectra, is better in this task than for the first one. Indeed, one could think that the complex geometry of the simulated experiment is likely to induce larger discrepancies than those found for the simpler experiment of task 1. In fact, the simple and well defined geometry of task 1 (point source) enables to measure the detailed physical spectrum, and the simulation should reproduce the detailed underlying physics. On the contrary, for the measurement of ^{241}Am radiation emitted from the phantom's bone, the muscle equivalent tissue hides, (or averages) the detailed shape of the spectrum. As a consequence, the MC simulations which were not so able to reproduce the detailed structure of the spectrum of task 1, are here able to reproduce a spectrum that can be considered as a "rough" spectrum. Of course, the low energy photopeaks are still badly reproduced for the same reasons that are explained in ***2.2.1.*** The experimental and computed spectra are shown in ***Figure 8***. From the simulated spectra, the detection efficiency (in units of count rate per Becquerel) at 59.5 keV was calculated for each participant. The detection efficiency is the key parameter since, in case of in-vivo measurement, it enables to relate the measured quantity (*i.e.* count rate) to the contaminant activity.

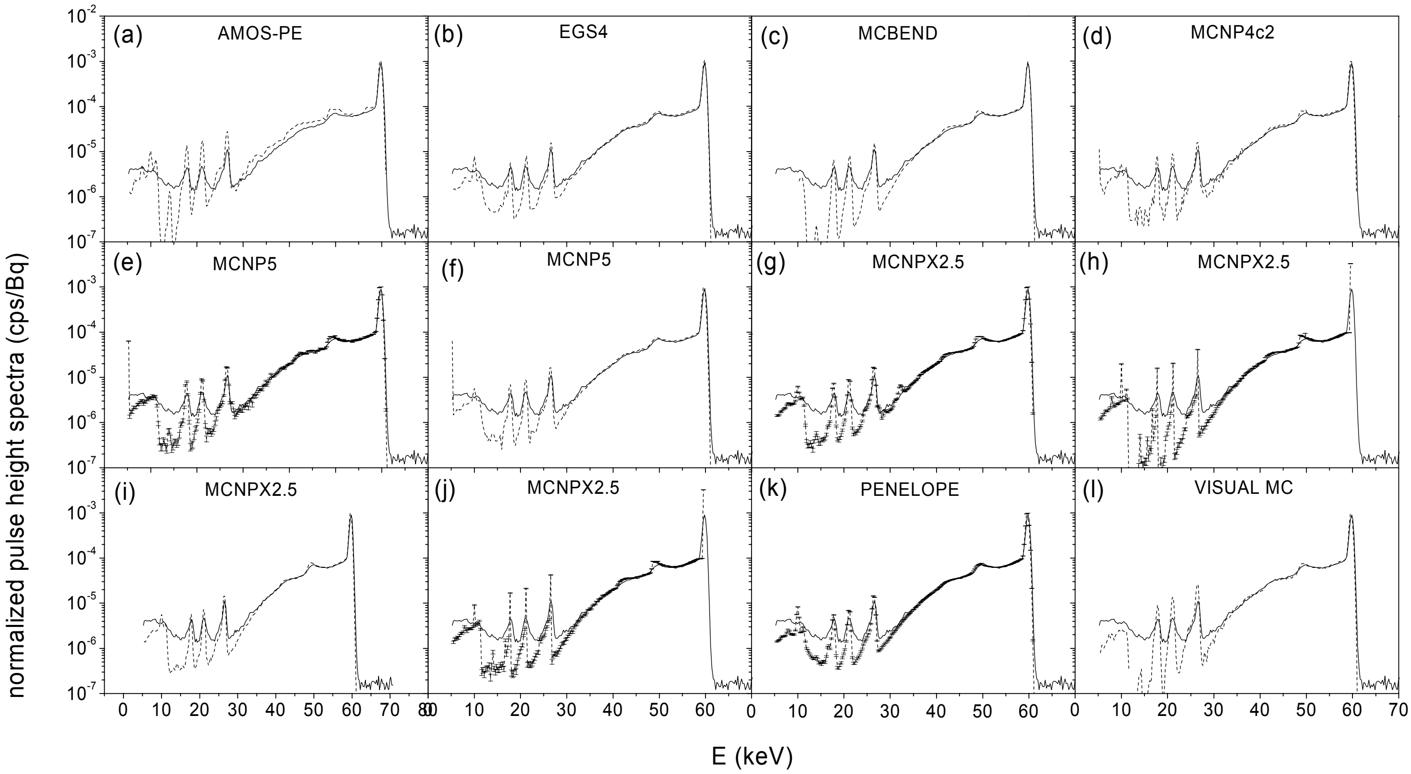


Figure 8: Simulated spectra of all partcipants, for Task b (dash curve is simulated and plain curve is experimental).

The resulting efficiencies are compared with the experimentally measured efficiency in ***Figure 9***. It can be noted that all the participants provided computed spectra whose analysis resulted in efficiency values larger than the experimental efficiency. Nevertheless, most of the participants have found detection efficiency not larger than 8% of the target experimental efficiency. The reasons for this overestimate have been discussed in [12] and it has been found that a systematic error of 1 cm in the stated vertical positioning of the detector just results in a systematic error of 7% in the computed efficiency. Nevertheless, it seems important to recall that an overestimate of the detection efficiency results in an overestimate of the activity of contaminants, which is questionable regarding the requirement of conservative activity assessments required by radioprotection basic principles.

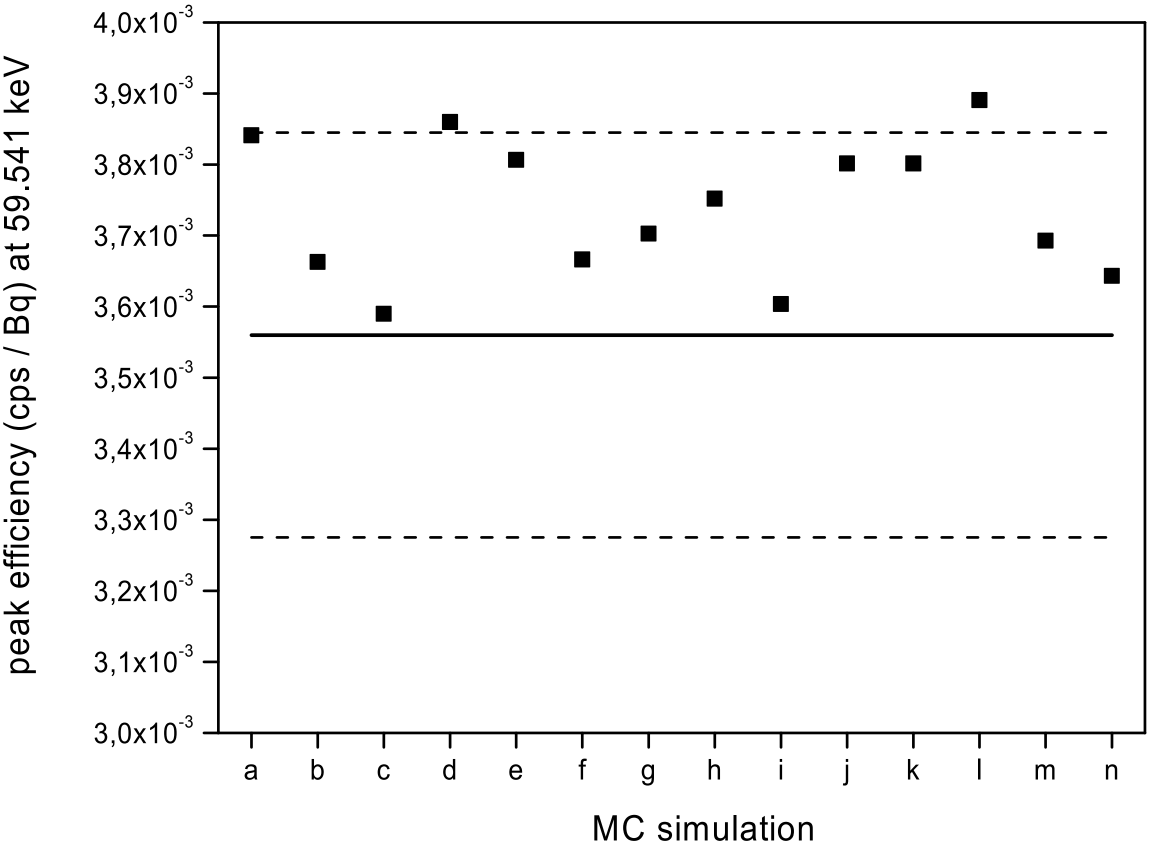


Figure 9: Detection efficiency for Task b, provided by the participants

3 THE INTERNATIONAL COMPARISON OF MEASUREMENTS AND MONTE CARLO MODELLING FOR AMERICIUM IN THE USTUR LEG PHANTOM

3.1.- Motivations

As described in the previous section, the sptiz knee phantom used in the intercomparison exercise does really represent a real contamination: it is made of muscle equivalent plastic and contains a bone phantom with a homogeneous distribution of americium in the bone equivalent material. however, it is known that after a contamination, americium does not deposit homogeneously in the bone but rather at the surface of the bone [13-15]. as a matter of fact, one can argue that the detection efficiencies obtained during measurement and simulations with this phantom are not representative and the detection efficiency provided with the help of this phantom should be used very carefully if a real case assessment was needed.

in the frame of the conrad contract and in collaboration with the ustur (united states transuranium and uranium registry) it was decide to work with the ustur leg phantom [5] which contain a real bone contaminated with americium coming from the body of a contaminated person. this ensures the best realism for calibration of in-vivo counting systems, especially when one deals with bone seekers radionuclides. this phantom is shown in figure 10.

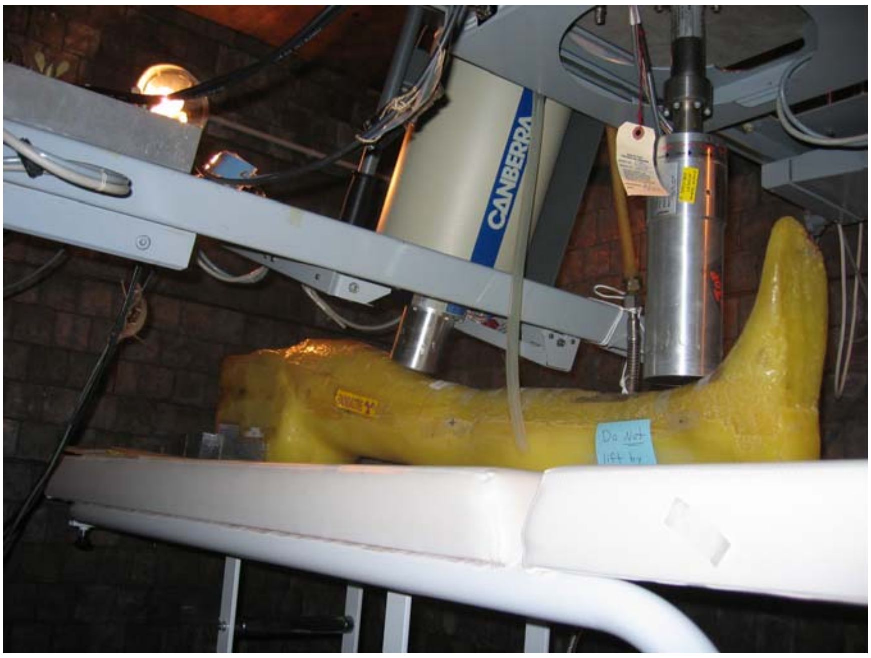


Figure 10: In-vivo measurements of the USTUR leg phantom with high purity Germanium detectors.

3.2.- Objectives

The objectives of this exercise are the same as those of the action carried out with the Spitz knee phantom; furthermore, in this case in vivo measurements have to be performed by participants using Germanium detectors, providing experimental values of detection efficiciency for intercomparison. The following points are the basis of the protocol:

1. *Comparison of measured efficiency along the leg*. The best counting geometry for measurement of activity will be discussed after the comparison of the participant's data.
2. *Computation of efficiency pattern along the knee*. A reference counting system, certainly the counting system of CIEMAT previously used, will be chosen. Computation at references points will be carried out for the purpose of comparison of computation between participants as well as the comparison of calculations with experimental data.
3. *Study of the detection efficiency changes induced by different activity patterns*. With a voxel phantom it is possible to fill the bone marrow (actually removed from the real phantom) with activity and it is also possible to change the composition of the bone marrow part into trabecular or bone. As a consequence the differences in the detection efficiency, induced by inhomogeneous and homogeneous activity distribution, can be studied by calculations over a modified voxel phantom.

3.3.- Participants

The following laboratories are participating to this exercise:

- IRSN, France
- CIEMAT, Spain
- GSF, Germany
- HML, Canada
- PNNL, USA

3.4.- Current status of the action

- The basis of the intercomparison protocol were discussed by members of the subgroup 5.3 during Montpellier meeting in 2006.

- The transportation of the Leg phantom from USA to Europe and between European laboratories has been organized by IRSN and PNNL.

- By the end of April 2007, the phantom was received at IRSN where measurements (cf. ***Figure 10***) and CT scans (***Figure 11***) were carried out.

- In December 2006 the reference voxel phantom was under construction at IRSN.

- By the end of June 2007, the phantom was received at CIEMAT where CT scans and measurements were carried out.
- In the beginning of October 2007, the phantom was received at GSF.
- The phantoms will then go to HML and will be then sent back to PNNL.
- The progress of the intercomparison was discussed by members of the subgroup 5.3 during Athens meeting in November 2007.
- Preliminary results and actions to be taken in 2008, have been discussed during the task-group meeting held in Paris, in January 2008.

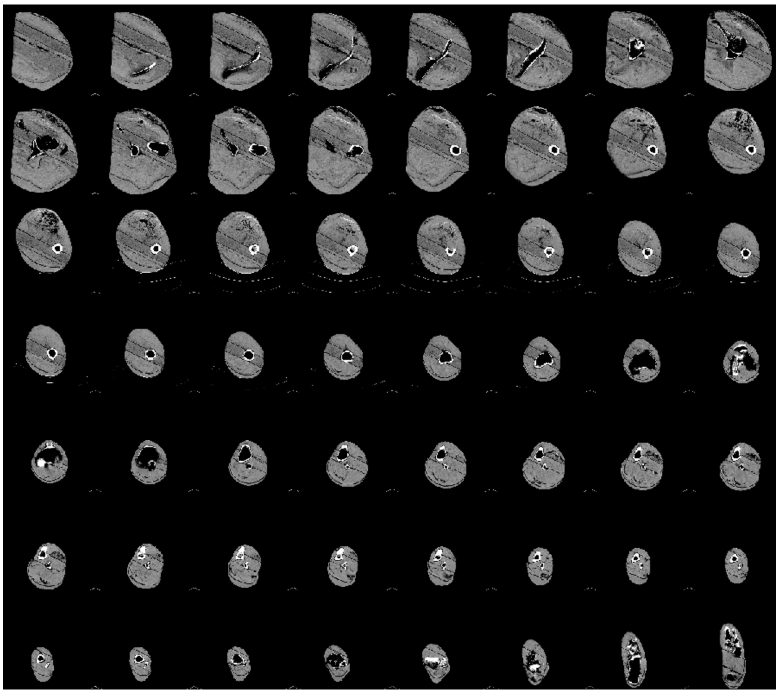


Figure 11: Medical images obtained after the CT scan of the USTUR leg phantom.

4 CONCLUSIONS AND PROSPECTS

The intercomparison exercise dealing with in-vivo measurement simulation of ^{241}Am in the Spitz knee phantom has been successful. On one hand, by the number of participants, which underlines the interest of the dosimetry community for topics related to Monte Carlo simulation in the framework of radioprotection or more generally, medical physics. On the other hand, by the collaboration between WP4 and WP5 CONRAD groups since it enabled to gather specialists from different fields where different Monte Carlo codes are traditionally used.

Indeed, the results presented during the Bologna workshop in October 2006, showed that exercises dealing with these topics were the most attractive. Moreover, the recent development of voxel phantoms devoted to accurate dosimetric assessment has revealed the need for intercomparison studies that enable participants to share their experience and discuss key issues.

This exercise thus evidenced that all Monte Carlo codes are of equivalent quality, when properly used, for the simulation of in-vivo counting measurements.

This intercomparison exercise was one of those for which the best agreement between participants was reached. This can be explained by the fact that the problem was very clearly stated, and that prior studies about detector modelling had not been included in the requested work.

Owing to the success of the intercomparison exercise with the Spitz knee phantom, IRSN and CIEMAT have planned to organize a similar exercise dealing with the in-vivo simulation of actinides in the lungs. For this purpose a reference counting system and the Livermore torso phantom will be used. This exercise will be undertaken after the achievement of the study with the DOE leg phantom.

The second intercomparison exercise with the USTUR Leg phantom is a more opened problem since it includes measurement studies and a study about the influence of Americium deposition inside the bone on the measurement calibration factors. This exercise has been limited to a few participants, mainly because of the difficulties of the phantom transportation. Most active institutes in the field of in-vivo counting have been included in this program.

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3.4.- CONRAD Task 5.4: Development of an Emergency Monitoring Network

Coordinator of Task T5.4: George Etherington (HPA, UK)

DELIVERABLE 5.4 - FINAL REPORT, FEBRUARY 2008

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This report from HPA Radiation Protection Division reflects understanding and evaluation of the current scientific evidence as presented and referenced in this document.

ABSTRACT

In the event of an accidental or deliberate release of radionuclides to the environment, individual monitoring and dose assessment may be needed for large numbers of people. The consequences of such incidents are not limited by national boundaries. However, within the European Union (EU), there is no coordinated strategy for individual monitoring and dose assessment and little exchange of information. The first action of Task 5.4 of the CONRAD project was to establish the EUREMON network, which aims to promote sharing of information between countries on plans and arrangements for individual monitoring. The network currently has 51 individual members from 22 EU countries, 8 non-EU countries and two international organisations. The network was subsequently used in a survey of plans and arrangements for emergency personal monitoring in EU countries. A report on the results of the survey is currently in preparation. Information is also being compiled on portable and transportable monitoring facilities and equipment in the EU.

CONTENTS

1 **Introduction** 180

2 **Establishing the network** 181

3 **Survey of current practice** 184

4 **Compilation of information on portable and transportable monitoring facilities**

5 **Planned developments** 187
  5.1 **Maintenance of the EUREMON network** 187
  5.2 **Analysis of the results of the survey** 187
  5.3 **Compilation of information on portable and transportable monitoring facilities** 187
  5.4 **Other possible initiatives** 188

6 **Conclusions** 188

APPENDIX A **Invitation to join the EUREMON network** 189

APPENDIX B **Leaflet explaining the aims of the network** 191

APPENDIX C **The survey questionnaire** 193

APPENDIX D **Invitation to EUREMON members to contribute to the survey** 209

APPENDIX E **Portable and transportable monitoring equipment in Finland** 208
  E1 Introduction 211
  E2 External Contamination Monitoring 211
  E3 Internal Contamination Monitoring 212

APPENDIX F **Portable and transportable monitoring equipment in France** 211
  F1 Introduction 215
  F2 External Contamination Monitoring 215
  F3 Internal Contamination Monitoring 216

APPENDIX G **Portable and transportable monitoring equipment in Spain** 218
  G1 Introduction 223
  G2 External Contamination Monitoring 224
  G3 Internal Contamination Monitoring 225

APPENDIX H **Portable and transportable monitoring equipment in the UK** 221
  H1 Introduction 227
  H2 External Contamination Monitoring 227
  H3 Internal Contamination Monitoring 228

1 INTRODUCTION

In the event of an accidental release of radionuclides (e.g. a reactor accident) or a deliberate release (e.g. a terrorist incident involving a radiological dispersion device (RDD)), individual monitoring and dose assessment may be needed for large numbers of people to identify those needing medical treatment, and to inform and reassure others. The affected population would include both members of the public and emergency workers responding to the incident. Such incidents always have repercussions across international borders. Even an incident such as the ^{210}Po poisoning incident in London in November 2006 (in which a single individual was targeted) resulted in the need for individual monitoring to be considered in at least 30 countries and carried on a significant number of people in many of these countries. However, within the European Union (EU), there is no coordinated strategy for internal dose monitoring and dose assessment, and little exchange of information. Task 5.4 of the CONRAD project was initiated in order to respond to the need to share information between countries on plans and arrangements for individual monitoring following the type of incident described above.

CONRAD (**CO**-ordinatio**N** Action for **RA**diation **D**osimetry) is an EC 6th Framework Programme Co-ordination Action sponsored by EURADOS (the European Radiation Dosimetry Group, http://www.eurados.org). The project commenced in April 2005 and concludes at the end of February 2008. Work Package 5 of CONRAD addresses issues relating to internal dosimetry, and is split into five tasks. The original objectives of Task 5.4 were:

1. Development of a network of people and organisations with responsibilities for emergency monitoring of people, and assessment of doses resulting from internal and external contamination
2. Sharing of information on current emergency monitoring and dose assessment methodologies
3. Collection and sharing of information on research and development (R&D) on these topics
4. Coordination of research and development work
5. Definition of needs for research, advice and training

In 2006, two of the organisations participating in Task 5.4 (HPA and STUK) contributed to a proposal in response to an EC 6th Framework Programme Call for Proposals[1] for a Specific Targeted Research Project (STREP) addressing the need for guidelines on emergency individual monitoring and medical treatment. Specifically, the Call requested proposals for projects to "...develop improved and more holistic approaches for the effective and more timely monitoring and treatment of populations exposed as a result of the malevolent use of radiation or radioactive material." The proposal was successful, and the project, TMT HANDBOOK[1], commenced in September 2006. The main aim of the project is to develop a practicable handbook for the effective and timely triage, monitoring and treatment of people exposed to radiation following a malevolent act. In support of this aim, TMT HANDBOOK aims to collect information from relevant organisations in the European Union on national arrangements for responding to incidents arising from the malevolent use of radiation or radioactive material.

---

[1] EC Call 2005/C 139/15, RADPROT 2005/6-3.3.4.1-2, June 2005

Given that the two projects are addressing related topics, and since CONRAD funds coordination of work carried out by participating organisations rather than research and development work, it was decided that CONRAD Task 5.4 should concentrate on establishment of the network (i.e. objective 1). It was also agreed that the network should be initially utilised for a survey of current practice aimed at meeting the objectives of both projects. The organisations participating in Task 5.4 also agreed to continue to share information on relevant research and development projects and coordinate such work where possible.

Participation in CONRAD Task 5.4 since April 2005 was as follows:

TABLE 1 Organisations participating in CONRAD Task 5.4

Organisation	Country	Full / Corresponding Member	Participants	Notes
HPA	United Kingdom	Full	George Etherington	
			Peter Pellow	From January 2006
			Alan Hodgson	From January 2006
			Neil Stradling	Till January 2006
STUK	Finland	Full	Tua Rahola	
			Maarit Muikku	
ENEA	Italy	Corresponding	Paolo Battisti	
CEA	France	Corresponding	Philippe Bérard	
IRSN	France	Corresponding	Cecile Challeton-de-Vathaire	
EdF	France	Corresponding	Bernard Le Guen	
NRPA	Czech Republic	Corresponding	Irena Malatova	

2 ESTABLISHING THE NETWORK

The network was given the acronym EUREMON; **EUR**opean **E**mergency **MON**itoring. It was decided that the network should include people with direct responsibility for monitoring and dosimetry of people affected as a result of an incident involving either the accidental release or the malevolent use of radiation or radioactive materials. Invitations were sent to selected people in five different groups:

---

[1] Contract No. FP6 - 036497

1. Contributors to a survey on monitoring practice carried out for an earlier project (the 5th Framework Programme project OMINEX)
2. EURADOS members
3. Participants in Work Package 5 of CONRAD
4. Members of EURADOS's harmonisation network
5. People known to be active in the area of interest to Task 5.4

The letter of invitation is reproduced in Appendix A.

The stated aims of the network are to collect and share information on: relevant national legislation; any international agreements or existing collaborations relating to monitoring and dose assessment; publications & reports describing strategies for internal and external contamination monitoring; publications & reports giving advice on therapy; equipment for internal/external contamination monitoring after accidental or deliberate releases; current dose assessment methodologies; and currently-available dose assessment software. The invitation letter was accompanied by a leaflet presenting the aims of the network. This leaflet is reproduced in Appendix B.

The EUREMON network currently has 51 individual members from 22 European Union (EU) countries, 8 non-EU countries and two international organisations. New members are still occasionally being recruited. Table 2 shows the membership at the end of October 2007. It has so far not been possible to recruit members from the following EU countries: Austria, Denmark, Latvia and Malta.

TABLE 2 EUREMON network membership (as of 29-10-2007)

Country	Name of recipient	Organisation
	European Union Countries	
Belgium	Christian Hurtgen	Belgian Nuclear Research Centre (SCK•CEN)
	Carlos Rojas-Palma	SCK•CEN
Cyprus	Stelios Christofides	Nicosia General Hospital
Czech Republic	Irena Malatova	National Institute of Public Health
	Helena Pospisilova	Head of WBC laboratory, National Radiation Protection Institute
Estonia	Monika Lepasson	Estonian Radiation Protection Centre
Finland	Maarit Muikku	Radiation and Nuclear Safety Authority (STUK)
	Tua Rahola	STUK
France	Philippe Berard	Commissariat à l'Energie Atomique (CEA)
	Cécile Challeton-de Vathaire	The Institute for Radiological Protection and Nuclear Safety (IRSN)
	Bernard Le Guen	LAM/SCAMT
Germany	Karl König	Federal Office of Radiation Protection (BFS)
	Klaus Henrichs	Siemens AG Corporate Radiation Safety and Dangerous Goods Transport
	Volker List	Forschungszentrum Karlsruhe, Medical Section

TABLE 2 EUREMON network membership (as of 29-10-2007)

Country	Name of recipient	Organisation
		(FZK/Med)
Greece	Eleftheria Carinou	Greek Atomic Energy Commission (GAEC)
	Virginia Koukouliou	GAEC
Hungary	Andor Kerekes	National Research Institute for Radiobiology and Radiohygiene (NRIRR)
	Roland Horvath	KFKI Atomic Energy Research Institute
Ireland	Lorraine Currivan	Radiological Protection Institute of Ireland (RPII)
	Michael Casey	Chief Physicist, Medical Physics and Clinical Engineering, St. Vincent's University Hospital
Italy	Paolo Battisti	Italian Agency for New technologies, Energy and the Environment (ENEA) Rome Headquarters
Lithuania	Birute Griciene	Radiation Protection Centre
Luxemburg	Nico Harpes	Ministere de la Sante
Poland	Pawel Krajewski	Central Laboratory for Radiological Protection
	Antonina.Cebulska-Wasilewska	The Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences
Portugal	João Alves	Instituto Tecnologico e Nuclear (ITN) Departamento de Protecção Radiológica e Segurança Nuclear (DPRSN) =ITN-DPRSN
	Luis Portugal	ITN-DPRSN
Romania	Constantin Milu	Romanian Society for Radiological Protection, Institute of Public Health
Slovakia	Dušan Ondriš	Nuclear Decommissioning company (JAVYS)
	Dušan Viktory	Public Health Authority of the Slovak Republic (Úrad verejného zdravotníctva Slovenskej republiky)
Slovenia	Nina Jug	Ministry of Health Slovenian Radiation Protection Administration (SRPA)
	Gregor Omahen	Institute of Occupational Safety
Spain	Eugenio Gil Lopez	Spanish Regulatory Body (Nuclear Safety Council).
Sweden	Jan Johansson	Swedish Radiation Protection Authority (SSI)
The Netherlands	Marianne Leenders	RIVM National Poisons Information Centre, National Institute for Public Health and the Environment
United Kingdom	George Etherington	Radiation Protection Division, Health Protection Agency (RPD-HPA)
	Paul Stock	Defence Science and Technology Laboratories
	International	
	Rodolfo Cruz-Suarez	IAEA
	Francesco D'ALBERTI	The European Commission Joint Research Centre in Ispra (C.C.R. ISPRA)
	NON European Union Countries	
Albania	Luan Qafmolla	Head of Radioactive Waste Management

TABLE 2 EUREMON network membership (as of 29-10-2007)

Country	Name of recipient	Organisation
		Laboratory, Department of Human and Environment Control and Protection Institute of Nuclear Physics
Belarus	Leanid Maskalchuk	Remediation Polluted Territories Laboratory, Head Joint Institute of Energy and Nuclear Research-"Sosny", National Academy of Sciences of Belarus
Iceland	Sigurður Emil Pálsson	Geislavarnir Rikisins (GR) Icelandic Radiation Protection Institute
Norway	Tor Wohni	Norwegian Radiation Protection Authority (NRPA)
	Lavrans Skuterud	NRPA
	Alicja Jaworska	NRPA
Russia	Valery Ramzaev	Institute of Radiation Hygiene
	Andrey Molokanov	State Research Center, Institute of Biophysics
Switzerland	Christophe Murith	Swiss Federal Office of Public Health
	Werner Zeller	Radiation Protection Division, Swiss Federal Office of Public Health
Turkey	Bengul Gunalp	Department of Nuclear Medicine, Gulhane Military Medical Academy and Faculty
Ukraine	Bonchuk Yuriy	Radiation Protection Institute, Kiev

3 SURVEY OF CURRENT PRACTICE

The survey of current practice was carried out by means of a questionnaire which was developed in such a way that it would meet the needs of both TMT HANDBOOK and of CONRAD Task 5.4. The survey has collected information on national strategic plans, monitoring strategies, availability of monitoring resources and capabilities for the interpretation of monitoring data, relevant national emergency exercises and research and development projects aimed at improving capabilities in this area.

HPA’s Radiation Protection Division (HPA-RPD) and STUK developed the initial version of the questionnaire. In designing the questionnaire, it was apparent that responses could be very variable in the amount of detail that could be provided by recipients, depending on the extent of planning for responding to malevolent acts in individual countries. It was therefore decided to ask a limited number of questions, but to make them open questions so the recipient would have freedom to give more or less information on a particular topic, as appropriate. To make clear the type of material required, example responses to each question were provided within the body of the questionnaire. Recipients were invited to reply by providing references or copies of existing published documents, and/or by providing a brief written response to each question.

Several rounds of consultation were required to ensure the questionnaire met the specified requirements, involving both participants in CONRAD Task 5.4 and TMT HANDBOOK. Those organisations participating in TMT HANDBOOK that contributed to the development of the questionnaire are listed in Table 3.

TABLE 3 TMT HANDBOOK participants contributing to the development of the questionnaire

Name of Organisation	Abbreviation	Organisation location
Belgian Nuclear Research Centre	SCK•CEN	Belgium
Norwegian Radiation Protection Authority	NRPA	Norway
Enviros Consulting Ltd.	Enviros	United Kingdom
Radiation and Nuclear Safety Authority	STUK	Finland
Health Protection Agency	HPA	United Kingdom
World Health Organisation	WHO	Geneva
Central Laboratory for Radiological Protection	CLRP	Poland

The full questionnaire is reproduced in Appendix C. It is prefaced by an introductory page explaining the purpose of the survey, how the information obtained from it will be used and how to complete it. Thirteen sections follow, labelled A-M, to which responses may be added.

Section A requests the name and address of the person completing the questionnaire and the organisation to which they are affiliated.

Section B asks the person replying to provide details (i.e. name, address, organisation and expertise) of people within their country who would have direct responsibility for monitoring or management of those people exposed to radiation as a result of an incident; and references and/or internet addresses (uniform resource locators (URL)) for any existing networks relating to the monitoring or management of people after an exposure.

Sections C-L requests information, including references to supporting papers or electronic documents where available, on both theoretical and practical topics that would need to be addressed in dealing with a radiation incident. Where appropriate, a brief description and/or examples of the type of information requested are included at the beginning of the section to help the responder. The section headings for C-L are:

Section C: Organisations and responsibilities

Section D: Relevant legislation, guidance, international agreements, etc

Section E: Recommendations on monitoring strategies

Section F: Equipment and facilities for emergency personal monitoring

Section G: Recommendations on methods for emergency personal monitoring

Section H: Dose assessment methodologies and software

Section I: Recommendations on medical management

Section J: Public information and communication

Section K: Emergency exercises

Section L: Research and development projects

Finally, Section M asks the responder to provide any other information that they consider relevant.

The questionnaire was finalised in June 2007 and sent to EUREMON members at the end of that month. The e-mail that accompanied the questionnaire is reproduced in Appendix D. In all, 51 questionnaires were sent to EUREMON members. Nineteen questionnaires were returned, which is approximately 37% of the total number sent out to all recipients. This is a slight under-estimate of the true return rate because in some instances questionnaires were sent to more than one person within an organisation in a particular country whereas a single questionnaire was returned for that organisation, e.g. STUK (Finland), GAEC (Greece) and NRPA (Norway). The overall response rate to the questionnaires is summarised in Table 4.

TABLE 4 Level of response to questionnaire (by 29-10-2007)

	Number of questionnaires
Sent	51
E-mail did not reach destination	3
Unable to help	2
No Reply	27
Returned Questionnaires	19
% Returned	37

4 COMPILATION OF INFORMATION ON PORTABLE AND TRANSPORTABLE MONITORING FACILITIES

Information has also been collected on portable and transportable monitoring facilities and equipment that could be used for individual monitoring in the event of an accidental or deliberate release of radioactive material resulting in internal or external contamination. Here “portable” means equipment that can be carried and operated by hand by an individual or a small team, while “transportable” means equipment that must be transported by a vehicle (e.g. a car, truck, train or aircraft). The aim is to compile information that can be made freely available to national authorities who may require assistance in carrying out individual monitoring of members of the public in the event of an emergency.

To date, information has been compiled in the form of short reports for four EU countries: Finland, France, Spain and the United Kingdom. These reports are appended to this report in Appendices E, F, G and H. Other EUREMON members will be invited to contribute similar reports. The compilation will then be published in the open scientific literature.

5 PLANNED DEVELOPMENTS

5.1 Maintenance of the EUREMON network

Now that the network has been established, it is important that it is maintained. This requires that regular contact be maintained with members, that information is fed back to members on how the information they have provided is being used, and that the membership is kept up-to-date. The latter requires that we are informed when members take on different responsibilities or retire, so that steps can be taken to identify new members. A regular e-mailed newsletter is one possible option for maintaining contact. There is also a need to improve communications with some Eastern European members, where in some cases e-mail has proved not to be reliable. Options for obtaining the limited funding necessary to maintain the network are being considered.

5.2 Analysis of the results of the survey

Analysis of the responses to the survey is currently nearing completion, and a report is in preparation. This report will be provided to all those who contributed to the survey. The survey will help to identify best practice, and so provide a basis on which to build a standardised approach in Europe for the monitoring, treatment and management of people in the event of an accidental or deliberate release of radioactive material to the environment. It will provide an input to the guidelines being prepared by the TMT HANDBOOK project.

5.3 Compilation of information on portable and transportable monitoring facilities

Other EUREMON members will be invited to contribute reports on portable and transportable monitoring facilities and equipment that could be used for individual monitoring in the event of an accidental or deliberate release of radioactive material resulting in internal or external contamination. These reports will be compiled, and submitted as a joint publication in the open scientific literature.

5.4 Other possible initiatives

At the final meeting of Task 5.4 during the CONRAD meeting held in October 2007 in Athens, a round table discussion was held of other possible initiatives that would promote emergency preparedness in the field of individual monitoring and dose assessment. The following issues were identified:

- The need for national surveys of inventories of available equipment suitable for emergency personal monitoring
- The development of desktop emergency exercises as a training tool for EUREMON members, focussed on monitoring, dose assessment, and management of members of the public
- The need for guidance on rapid in vitro analysis methods
- The need for dose assessment software appropriate for exposures received by members of the public, including assessment of absorbed doses received over short periods
- The need for guidance on the use of Prussian Blue for enhancing the clearance of radiocaesium, aimed at limiting exposures of members of the public.
- The promotion of cooperation and sharing of resources (e.g. bioassay laboratories) between EU countries

6 CONCLUSIONS

A network of people with direct responsibility for monitoring and dosimetry of people in the event of a radiological emergency has been established. The stated aims of this network (named EUREMON) are to collect and share information on: relevant national legislation; any international agreements or existing collaborations relating to monitoring and dose assessment; publications & reports describing strategies for internal and external contamination monitoring; publications & reports giving advice on therapy; equipment for internal/external contamination monitoring after accidental or deliberate releases; current dose assessment methodologies; and currently-available dose assessment software. The EUREMON network currently has 51 individual members from 22 EU countries, 8 non-EU countries and two international organisations.

In collaboration with participants in the TMT HANDBOOK project, a survey has been carried out to collect information from EUREMON members on these topics. A report on the results of the survey is currently in preparation.

Information is also being compiled on portable and transportable monitoring facilities and equipment in Finland, France, Spain and the United Kingdom. EUREMON members will be invited to contribute information for other EU countries. The information collected will form the basis for a joint publication in the open scientific literature.

APPENDIX A Invitation to join the EUREMON network

European Radiation Dosimetry Group EURADOS

Health Protection Agency

STUK Radiation and Nuclear Safety Authority

Dear Colleague,

EUREMON: EURopean Emergency MONitoring network

We are members of the European Radiation Dosimetry Group (EURADOS), and are working within a European Commission 6th Framework Programme project named CONRAD [3]. Specifically, we are participants in Work Package 5 of CONRAD, "Coordination of Research in Internal Dosimetry". We are writing to you to ask for your assistance with our work.

In the event of a malevolent (deliberate release) incident involving release of radioactive material or radiation exposure, there would be a need for prompt monitoring of potentially exposed people. In our view, there is an urgent need to improve sharing of expertise and information within Europe on this topic.

Therefore, we wish to set up a network of people who have direct responsibility for monitoring and dosimetry of potentially contaminated people after such an event. This letter is aimed at identifying people with an appropriate level of expertise in internal and/or external dose monitoring. We wish to identify no more than two people in each country.

We are contacting selected people who (a) assisted us with an earlier project (the 5th Framework Programme project OMINEX), or (b) are EURADOS members, or (c) are participants in Work Package 5 of CONRAD, or (d) are members of EURADOS's harmonisation network, or because we know of their work in this area.

If you are willing to join our network, could you please complete the attached Contact Information Form, which requests contact details and brief information (2-3 sentences only) on your responsibilities and experience in this area. We would like to circulate the names and positions of network members within the network. Please indicate on the attached form if you do not wish us to do this. Your e-mail address will not be provided to anyone else, and other information you provide us will not be circulated unless you give your explicit permission.

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[3] CONRAD – “Coordinated Network for Radiation Dosimetry”

If you believe you are not an appropriate contact for your country, we would be very grateful if you would provide an e-mail address for an appropriate person to whom we could forward this request.

Further information on the aims of the network is attached.

Mª Antonia
Lopez

George Etherington, HPA
Tua Rahola, STUK
M.A. Lopez, Chair of CONRAD WP5 "Internal Dosimetry", EURADOS

Yours sincerely,

Attachments:

- Aims of the EUREMON network
- Contact Information Form

APPENDIX B Leaflet explaining the aims of the network

European Radiation Dosimetry Group EURADOS

Health Protection Agency

STUK Radiation and Nuclear Safety Authority

Aims of the EUREMON (EURopean Emergency MONitoring) network

Sharing of information on current strategies and methodologies

We aim to collect and share information on:

- relevant national legislation
- any international agreements or existing collaborations relating to monitoring and dose assessment
- publications & reports describing strategies for internal and external contamination monitoring
- publications & reports giving advice on therapy
- equipment for internal/external contamination monitoring after accidental or deliberate releases
- current dose assessment methodologies
- currently-available dose assessment software

Sharing of information on relevant research and development (R&D) projects

We aim to collect and share information on:

- new approaches to monitoring
- new methodologies for dose assessment and interpretation of data
- software currently in development

Definition of needs for research, advice and training

We will use the information collected to define needs for:

- new dose assessment methodologies
- future research and development work
- documents giving advice on strategies, equipment, dose assessment methodologies, etc
- needs for training

The results of the project will be published and will be provided to all network members. This will include an analysis of the information provided by network members.

APPENDIX C The survey questionnaire

The questionnaire sent out to recipients is reproduced below.

Monitoring, management and treatment of members of the public and emergency workers after accidental or deliberate releases of

Purpose of this questionnaire

This is a request for information on the current status of arrangements for the triage [1], monitoring [2] and treatment of members of the public and emergency workers after accidental or deliberate [3] releases of radionuclides or exposure to radiation. Topics of interest to us include national strategic plans, monitoring strategies, availability of monitoring resources, capabilities for the interpretation of monitoring data, recommendations on medical management, relevant national emergency exercises, and research and development projects aimed at improving capabilities in this area.

How the information will be used

The information will be used in two 6th Framework Programme projects part-funded by the European Commission:

TMT HANDBOOK (*http://www.tmthandbook.org*) will provide a practicable handbook for the effective and timely Triage, Monitoring and Treatment (TMT) of people following a malevolent act. This is a Specific Targeted Research Project. (Contract no: FP6 - 036497)

CONRAD (Task 5.4) aims to collect and share information on the topics listed above, and also aims to define needs for research, advice and training. This is a Co-ordination Action sponsored by EURADOS (European Radiation Dosimetry Group). (Contract no: FP6 - 12684)

The information you provide will make a valuable contribution to both projects. Individuals, organisations or countries providing information will not be identified in any reports or publications issued unless permission is explicitly given.

What to do now

You only need to answer those questions that are within your area of expertise. Please enter your responses in the fields shaded in light grey. The preferred language is English. Please return the completed questionnaire by e-mail to: peter.pellow@hpa.org.uk. Alternatively, you may fax it to the Health Protection Agency, for the attention of Dr P G D Pellow (++44 1235 833891).

Thank you for your assistance.

Explanatory notes

1. “Triage” – the use of simple procedures to prioritise people rapidly for further actions, including monitoring and treatment, in order to maximise the effective use of resources.
2. “Monitoring” – measurements of external radiation fields, external contamination or internal contamination; and the interpretation of such measurements in terms of radiation doses to the individual. The use of cytogenetics for biological dosimetry is included. The various types of monitoring are referred to generically as “emergency personal monitoring”.
3. That is, the malevolent use of radioactive material in a public place.

A. Personal information

Title	Please select
Family name	
First name(s)	
Job title	
Organisation	
Country	
Address	
Telephone no.	
FAX no.	
e-mail address	

Information is requested below on eleven specific topics (B-L). For each topic, we have provided a brief description and/or examples of the type of information requested (although these examples are not intended to be comprehensive). You may respond by providing references or copies of existing published documents, and/or by providing a brief written response.

If you believe that some questions in this questionnaire would be better answered by another person, either pass the questionnaire to that person when you have completed what you can, or give their name in your response to question B, identifying the question(s) in the "Area of expertise" field.

B. Other contacts in your country

Brief description of information requested:

We wish to identify people in your country with direct responsibility for:

(a) monitoring (or establishing plans for monitoring) of people who may have been contaminated with radioactive material or exposed to radiation in the event of an accidental or deliberate release;

or

(b) management of people who may have been contaminated with radioactive material or exposed to radiation after such an event.

Their expertise is likely to be in monitoring, dosimetry, radiation emergency medicine and/or emergency planning. Please provide contact information for any people other than yourself who have such responsibilities *.

Title	Please select	Please select
Family name		
First name(s)		
Job title		
Organisation		
Country		
Address		
Telephone no.		
FAX no.		
e-mail address		

Area of expertise:

References and/or internet address (URL) for information on any existing networks:

* If you can provide additional names, please provide the information listed above in a separate document.

C. Organisations and responsibilities

Brief description of information requested:
Please explain briefly the roles and responsibilities of organisations that are responsible for the planning, co-ordination and execution of arrangements for monitoring, management and treatment of members of the public. What are the relationships between the various organisations involved?

Examples:

In England and Wales, the National Health Service (NHS) has responsibility for initiating and supporting the public health response and maintaining the corresponding major incident plans. The NHS co-ordinates public health resources at the incident scene, provides the Ambulance Service and hospital operational response, provides emergency care and treatment, and supplies community services and resources. The government Department responsible for the NHS is the Department of Health (DH). DH puts legal duties on, and provides guidance to, the NHS. The Health Protection Agency (HPA) provides advice and support to the NHS at local, regional and national levels on chemical, biological, radiological and nuclear incidents. The Radiation Protection Division of the HPA is responsible for co-ordinating radiation monitoring resources that are made available by HPA and other organisations (including nuclear site operators).
Further information is given in the DH document “Emergency planning and response to major incidents: summary of roles and responsibilities”, currently available at: http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_4006959 or by searching for “Emergency planning and response” at http://www.dh.gov.uk.

Your response:

References and/or internet address (URL) from which documents can be downloaded:

D. Relevant legislation, guidance, international agreements, etc.

Brief description of information requested:

Please provide information on any national legislation or guidance that is relevant to the planning or performance of emergency personal monitoring in your country. Is use made of international guidance (e.g. IAEA publications)? If so, give references. Please identify any international agreements (perhaps with neighbouring countries), or existing international collaborations between institutes, that are relevant to the planning or performance of emergency personal monitoring.

Examples:

The UK Civil Contingencies Act 2004, http://www.ukresilience.info/preparedness/ccact.aspx. This Act of Parliament is concerned with civil protection in the event of any emergency. It specifies a statutory framework of roles and responsibilities for local responders, and addresses the emergency powers that might need to be introduced in the event of the most serious emergencies. It does not specifically address emergency personal monitoring.
The provision of international assistance in the case of nuclear or radiological incidents or emergencies is described in: IAEA Response Assistance Network, IAEA-EPR-RANET (2006). http://www-pub.iaea.org/MTCD/publications/PDF/Ranet2006_web.pdf. Arrangements for providing international assistance are described in: RANET Assistance Action Plan, IAEA-EPR-RANET, Attachment 1 (2006).
http://www-pub.iaea.org/MTCD/publications/PDF/Ranet2006_att1_web.pdf
A number of other publications from international agencies provide useful guidance:
Manual for First Responders to a Radiological Emergency, IAEA-EPR-First Responders (2006). Co-sponsored by CTIF, IAEA and WHO.
http://www-pub.iaea.org/MTCD/publications/PDF/EPR_FirstResponder_web.pdf
Arrangements for Preparedness for a Nuclear or Radiological Emergency, IAEA Safety Guide GS-G-2.1 (2007). Co-sponsored by FAO, IAEA, ILO, PAHO, OCHA and WHO.
http://www-pub.iaea.org/MTCD/publications/PDF/Pub1265_web.pdf
Method for Developing Arrangements for Response to a Nuclear or Radiological Emergency, IAEA-EPR-Method (2003).
http://www-pub.iaea.org/MTCD/publications/PDF/Method2003_web.pdf

Your response:

References and/or internet address (URL) from which documents can be downloaded:

E. Recommendations on monitoring strategies

Brief description of information requested:

Please provide information on any published recommendations on emergency personal monitoring strategies.

The term "monitoring" could include measurements of external radiation fields, external contamination, internal contamination or the use of cytogenetics for biological dosimetry, depending on the scenario.

Monitoring strategies address the following issues:

- criteria for selection of people for initial monitoring
- the use of monitoring for screening purposes
- criteria for triage of people for:
  - (a) medical intervention
  - (b) decontamination
  - (c) further monitoring
- choice of monitoring methods for different scenarios
- the use of monitoring measurements for assessment of radiation doses
- specifications of dose information required from monitoring
- requirements for long-term follow-up monitoring
- protocols for reporting of results
- recommendations for methods for reassuring concerned people

Examples:

NHS Emergency Planning Guidance (2005) (UK). Download “NHS Guidance – incidents involving radioactivity”, currently available at:
http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_4121072
Radiation monitoring strategy: factors to be considered. Lahtinen, J. *Radiat Prot Dosim* **109** 79-82 (2004).

Your response:

References and/or internet address (URL):

F. Equipment and facilities for emergency personal monitoring

Brief description of information requested:

Please provide information on any published recommendations on equipment and facilities for measurements of external radiation fields, external contamination, internal contamination or the use of cytogenetics for biological dosimetry. For internal contamination monitoring, please differentiate between *in vivo* (direct) and *in vitro* (indirect) measurement facilities. Have any surveys of monitoring resources available in your country been carried out? Is there an inventory of appropriate monitoring equipment in your country ? If there is no published information, please provide what information you can on the monitoring equipment and facilities that would be deployed in your country.

Examples:

IAEA has specified technical and administrative guidelines for Competent Authorities (CAs) when planning and preparing National Assistance Capabilities (NACs) for responding to a nuclear or radiological incident or emergency in: RANET Technical Guidelines, EPR-RANET, Attachment 3 (2006). Guidelines are given for required expertise, staffing, monitoring equipment and assessment capability.
http://www-pub.iaea.org/MTCD/publications/PDF/Ranet2006_att3_web.pdf

Your response:

References and/or internet address (URL):

G. Recommendations on methods for emergency personal monitoring

Brief description of information requested:

Please provide information on any published recommendations on monitoring methods (that is, on the use of the equipment and facilities mentioned in question F) for emergency personal monitoring. Are there any formal quality assurance requirements that apply to the use of equipment and facilities for emergency personal monitoring? If there is no published information, please provide what information you can on monitoring methods in your country.

Examples:

IAEA has published a Technical Document on this subject: Rapid Monitoring of Large Groups of Internally Contaminated People Following A Radiation Accident, IAEA TECDOC Series No. 746 (1994). http://www-pub.iaea.org/MTCD/publications/pdf/te_746_web.pdf

Useful guidance is provided in a number of other publications:

Towards a standardization of biological dosimetry by cytogenetics. Voisin P *et al*. *Cell Mol Biol* **48** no. 5, 501-504 (2002).

The role of cytogenetics in early triage of radiation casualties. Lloyd D C *et al*. *Applied Radiation and Isotopes* **52** 1107-1112 (2000).

International intercomparison for criticality dosimetry: the case of biological dosimetry. Roy L *et al*. *Radiat Prot Dosim* **110** no. 1-4, 471-476 (2004).

ISO 19238:2004. “Radiation protection - Performance criteria for service laboratories performing biological dosimetry by cytogenetics". This standard provides criteria for quality assurance and quality control, evaluation of the performance and the accreditation of biological dosimetry by cytogenetic service laboratories.

Your response:

References and/or internet address (URL):

H. Dose assessment methodologies and software
Brief description of information requested: Please provide information on dosimetric methods that would be used for assessment of internal doses and dose to the skin in the event of an accidental or deliberate release. Dose assessments could be based on measurements of external radiation fields, external contamination, internal contamination or the use of cytogenetics for biological dosimetry, depending on the scenario. For assessments of internal doses, would assessments be made using exclusively default assumptions about biokinetic model parameter values? If so, please give further information.
Examples: For internal dose assessments: models described in ICRP Publications 60, 66, 67, 69, 71, 72, as implemented in the software package IMBA. Birchall, A. *et al*. IMBA Expert™: internal dosimetry made simple. *Radiat. Prot. Dosim.* **105** no. 1-4, 421-425 (2003). For biodosimetry: Cytogenetic biodosimetry for radiation disasters: recent advances. Prasanna P-G *et al*. (2005). NATO Human Factors and Medicine Research Task Group 099 “Radiation Bio-effects and Countermeasures". http://www.afrri.usuhs.mil/www/outreach/pdf/prasanna_NATO_2005.pdf Parameters affecting EPR dose reconstruction in teeth. Romanyukha A A *et al*. *Applied Radiation and Isotopes* **62** no.2, 147-154 (2005). doi:10.1016/j.apradiso.2004.08.039
Your response:
References and/or internet address (URL):

I. Recommendations on medical management

Brief description of information requested:

Please provide information on any published guidance for medical management of :

- external exposure, including diagnosis, treatment and follow-up of acute radiation syndrome, local radiation injuries and combined injuries.
- internal contamination, including procedures for the removal of radionuclides from the body (decorporation). Are there specific recommendations for the management of contaminated casualties (i.e. contaminated people who also have physical injuries)?
- mental health in radiation emergencies (prevention and/or treatment of psychological impact).
- long-term follow-up of people exposed to ionising radiation.

Please provide what information you can on the following specific questions:

(a) What is the capacity of your country for treating patients with acute radiation syndrome ? e.g. in laminar flow / isolation facilities, cell therapy units.

(b) What criteria are used for taking decisions about treatment of acute radiation syndrome? e.g. criteria based on dose estimates, clinical parameters.

(c) What is the capacity of your country for treatment of cutaneous radiation syndrome? e.g. in burns units, using reconstructive surgery services.

(d) What criteria are used for taking decisions about treatment of local radiation injuries? e.g. criteria based on dose modelling, clinical evolution.

(e) What is the capacity of hospitals in your country for dealing with contaminated casualties?

(f) Would decisions on treatment of contamination be made without knowledge of the radionuclide to which an individual may have been exposed, or knowledge of assessed doses?

(g) What criteria are used for taking decisions about treatment of contamination? e.g. action levels.

(h) Would different criteria be applied for emergency services workers and members of the public?

(i) What protocols for treatment of internal contamination (e.g. decorporation agents, blocking agents) would be used in the immediate phase after an incident? For each treatment, which radionuclide contaminant(s) would these protocols be used for?

(j) Please give the same information for treatment protocols, decorporation agents and blocking agents used in the longer term?

(k) What factors determine the length of treatment for decorporation?

(l) What is the legal status of the agents that might be used for treatment of radiation victims e.g. cytokines, growth factors, decorporation agents, blocking agents (for instance, are they licensed for the use envisaged)?

(m) What information is available on stocks and availability of specific supplies e.g cytokines, growth factors decorporation and blocking agents?

(n) Are mental health care teams part of the response in radiation emergencies?

(o) Does any guidance exist on Public Health response in radiation emergencies?

Examples: The following references provide useful resources: Guidebook for the Treatment of Accidental Internal Radionuclide Contamination of Workers. *Radiat Prot Dosim* **41** no. 1 (1992). Decorporation Treatment - Medical Overview. R. Wood *et al*. In Decorporation of Radionuclides from the Human Body. *Radiat Prot Dosim* **87** no. 1, 51-57 (2000). Radiation Event Medical Management: Guidance on Diagnosis & Treatment for Health Care Providers (2007). U.S. Department of Health and Human Services; Office of the Assistant Secretary for Preparedness and Response. http://www.remm.nlm.gov Generic Procedures for Medical Response during a Nuclear or Radiological Emergency, IAEA-EPR-Medical (2005). Co-sponsored by IAEA and WHO http://www-pub.iaea.org/MTCD/publications/PDF/EPR-MEDICAL-2005_web.pdf Diagnosis and Treatment of Radiation Injuries, IAEA Safety Report Series No. 2 (1998). Co-sponsored by IAEA and WHO. http://www-pub.iaea.org/MTCD/publications/PDF/P040_scr.pdf Consensus conference on European preparedness for haematological and other medical management of mass radiation accidents. Gorin N C *et al*. *Ann Hematol*. **85** no. 10, 671-679 (2006). Follow-up of delayed health consequences of acute accidental radiation exposure. IAEA TECDOC Series No. 1300 (2002). Co-sponsored by IAEA and WHO. http://www-pub.iaea.org/MTCD/publications/PDF/te_1300_web.pdf
Your response:
References and/or internet address (URL):

J. Public information and communication

Brief description of information requested:
Please provide information on any guidelines addressing public information and communication strategies.

Examples:

IAEA provides some useful sample media releases in Appendix 2 of the Manual for First Responders to a Radiological Emergency, IAEA-EPR-First Responders (2006). http://www-pub.iaea.org/MTCD/publications/PDF/EPR_FirstResponder_web.pdf
A basis for explanations to the public about the risks to health of radiation exposures is described in Appendix 4 (Plain Language Explanation of Risks) of the IAEA publication Development of an Extended Framework for Emergency Response Criteria, IAEA TECDOC Series No. 1432 (2005). http://www-pub.iaea.org/MTCD/publications/PDF/TE_1432_web.pdf

Your response:

References and/or internet address (URL):

K. Emergency exercises

Brief description of information requested:
Please provide information on any recent emergency exercises in which emergency personal monitoring and/or medical treatment of contaminated people has been carried out, either in reality or as a "desktop" exercise. What scenarios for malevolent incidents have been considered? How effective were these exercises in testing monitoring, management and treatment of people? What were the important lessons learned relating to these issues?

Examples:

In the UK, at least one major (“Level 3”) civil exercise is carried out each year which tests the national response. Emergency personal monitoring is exercised “in reality” in about 1 in 3 of these exercises, with a desktop exercise of the response being carried out during the remaining national exercises. Some exercises (notably at BNFL Sellafield) have involved the management and monitoring of over 100 volunteers acting as members of the public. When the release includes high yield gamma-ray emitting radionuclides, HPA’s transportable body monitor is usually deployed. In some exercises, monitoring teams are deployed by HPA, nuclear site operators and the NHS to carry out external contamination monitoring and (where appropriate) iodine-in-thyroid monitoring. When appropriate, HPA exercises its role of coordinating the use of monitoring resources provided by other organisations. One of the main difficulties is to exercise emergency personal monitoring on a realistic time scale within the constraints of a 1- or 2-day exercise. Thus, exercises are most useful for exercising the management of members of the public and personal monitoring in the early phases of an incident. Some exercises have identified the need for readily-accessible agreed guidance relating to decorporation of radionuclides.

Your response:

References and/or internet address (URL):

L. Research and development projects

Brief description of information requested:

Please provide information on any current or planned research and development project that is relevant to emergency personal monitoring that you are aware of, together with contact details for the project leader / co-ordinator. Please also provide references to published work.

Examples:

TIARA (Treatment Initiatives After Radiological Accidents). A project within the EU's Preparatory Action for Security Research. This project is being carried out by a consortium of medical officers and scientists for the purpose of : providing guidance on dose assessment and efficacy of treatment; foreseeing the operational needs for treating persons in the event of mass casualties; monitoring scientific developments in research into new treatments; and providing training on these issues. Project coordinator: Dr F Menetrier, CEA Fontenay-aux-Roses, florence.menetrier@cea.fr

Your response:

References and/or internet address (URL):

If you have any other comments, please complete section M.

M. Any other information
Brief description of information requested: Please provide any other information that you think is relevant. We would particularly welcome your views on how best to share expertise, and co-ordinate and harmonise the monitoring, management and treatment of people across the European Union.
Your response:
References and/or internet address (URL):

APPENDIX D Invitation to EUREMON members to contribute to the survey

This Appendix presents the invitation e-mail that was sent with the questionnaire to EUREMON members.

(a) E-mail invitation to complete questionnaire sent to EUREMON members:-

Subject line:

Request for information from EUREMON members

Message body:

Dear EUREMON member

Recently, we invited you to join the EUREMON (EURopean Emergency MONitoring) network. A copy of the network's aims is attached.

One of the aims is to collect and share information on topics related to emergency monitoring. Would you please assist us now by completing the attached questionnaire on "Monitoring, management and treatment of members of the public and emergency workers after accidental or deliberate releases of radionuclides or exposure to radiation". The purpose of the survey, the uses we will make of the information received, and instructions on how to complete the questionnaire are explained on the first page of the questionnaire.

Thank you for your assistance. It would be helpful to us if you could respond by ***(give date, 3 weeks from date sent)***

Yours sincerely,

P G D Pellow	G Etherington
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APPENDIX E Portable and transportable monitoring equipment in Finland

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E1 INTRODUCTION

This document summarises the portable and transportable monitoring equipment that would be available for monitoring members of the public following an accidental or deliberate release of radioactivity. It covers instruments for measurement of external and internal contamination. Some of the information is taken from a recent survey of *in vivo* monitoring resources in the Nordic countries [1]. No such survey has been done for external contamination monitoring. There are two nuclear sites in Finland. The nuclear site operators also have instruments for monitoring. Help will be offered from the NPP's in case of accidents if operational functions allow**.** Also the military would help with monitoring of members of the public in case of emergency.

E2 EXTERNAL CONTAMINATION MONITORING

E2.1 Hand-held instruments

At all hospitals there are hand held instruments and persons trained persons to do monitoring,

The emergency and rescue forces have dose rate meters and some personal dose meters.

The nuclear power plants are well equipped with instruments and the personnel trained to use them.

Research centers, universities and other institutions using radioactive sources are obliged to have measuring equipment. No common register has been developed so far.

The military has monitors and trained personnel as well but no details on instrumentation are available.

Typical instruments are RADOS 120 or DGM Turva. No common register of these monitors has been established so far.

In addition to the activities of the authorities, civil defence involves the self-preparedness of companies and other organisations, property owners, and citizens. Civil defence shelters must afford protection from radiation, gases and conventional weapons. They are located in residential and public buildings. Of the shelters, 40 per cent are associated with workplaces and 60 per cent with dwellings. Many of these shelters, but probably not all, are equipped with hand held monitors of the type RADOS 120 or DGM Turva.

STUK has twelve instruments ATOMTEX 1117M for alpha, beta, gamma monitoring and some tens of rate and total dosemeters.

E2.2 Portal Monitors

Portal monitors are installed at all borders both for control of passengers and for vehicles but none of these are portable.

E3 INTERNAL CONTAMINATION MONITORING

E3.1 Iodine in thyroid monitoring

Finland is divided into 20 health care districts and the 21st district is the Åland islands in the west. At 27 hospitals there are monitors for I-131 uptake measuremeents of the thyroid. Most of those monitors show count rates and are not calibrated for content of iodine. The hospitals also have gamma cameras but they are better suited for whole-body than for thyroid monitoring. More information on that can be found in the BOK-2.1.2 report [2].

STUK as the responsible body for radiological emergency preparedness has lately obtained 35 thyroid monitors intended for direct measurements in emergency situations. Ten are of type Inspector 1000 by Canberra and the rest are RKG-AT1320 monitors made by company Atomtex [3]. The thyroid monitor consists of a detector NaI(Tl) crystal, control unit and lead collimator. The monitors work as spectrometers making it possible to do real time spectrum analysis in the field. The collected spectrum is shown on the display of the control unit. It is possible to store spectra in the detection unit, from where they can be later on transferred to a PC.

Fifteen Atomtex thyroid monitors have been distributed to the university and regional hospitals to be used at Nuclear Medicine departments by physicists that are familiar with this type of equipment. The users are part of an emergency network and they have been trained at STUK.

E3.2 Whole body monitoring

In Finland there are four whole-body monitoring systems. At STUK there are two whole-body counters: one stationary (scanning bed) with four NaI(Tl) detectors and three HPGe-detectors and one mobile unit with two HPGe-detectors in modified chair geometry installed in a truck. At the University of Helsinki there are one stationary and one mobile unit with NaI(Tl) detectors but these two are not used routinely.

STUK has obtained five Atomtex RKG-AT1320 monitors for simple whole-body measurements in field conditions [3]. The monitor is similar to the RKG-AT1320A thyroid monitors. Three calibrations (adult, teenager and child) have been made using the St. Petersburg whole-body phantom with ^{137}Cs and ^{40}K rods in it. The measurement is done in a simple lap geometry, also called the Palmer geometry. The person to be measured sits on a chair and holds the detector in his lap close to the stomach, bending slightly over the detector.

References

[1] Rahola, T., Muikku, M., Falk, R., Johansson, J., Liland, A. and Thorshaug, S. Assessment of internal doses in emergency situations. (Roskilde, Denmark: Report NKS-128) (2006).

[2] Rahola, T., Falk, F. and Isaksson, M. Summaries of studies carried out in the NKS/BOK-2 project: NKS/BOK-2.1.2 Metodhandbok: Mätning av radioaktiva ämnen i människa i beredskapssituationer (in Swedish). (Roskilde, Denmark: Report NKS-35). pp. 107–121 (2002).

[3] M. Muikku and T. Rahola. Improvement of the measuring equipment used in the assessment of internal doses in emergency situations, (electronic version) Radiation Protection Dosimetry (2007), ncm282

APPENDIX F Portable and transportable monitoring equipment in France

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Institut de Radioprotection et de sûreté Nucléaire, France

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F1 INTRODUCTION

This document summarises the portable and transportable monitoring equipment that would be available in France for monitoring members of the public following an accidental or deliberate release of radioactivity. It covers instruments for measurement of external and internal contamination as well as mobile laboratories for radiochemical analysis.

F2 EXTERNAL CONTAMINATION MONITORING

F2.1 Hand-held instruments

Equipment available at the French Institute for Radiological Protection and Nuclear Safety (IRSN) and at the French Defence Radiation Protection Service (SPRA)

The department for radiological protection operations and assistance of IRSN (SIAR) has about 100 instruments available for external monitoring for gamma, beta and alpha contamination. An external contamination control system is also available in the new mobile vehicle for body counting equipped with Ge detectors. It consists of a hand-held radiometer (Radagem 2000) with an alpha beta probe. The dose rate scale is comprised between 0.3 μSv/h and 100 mSv/h.

Equipment for external detection of contamination is also available at SPRA. It includes beta, gamma and alpha monitoring instruments.

Others equipment available in France

The fireman units are directly involved in case of accidental or deliberate release of radioactivity. For that purpose, specialized intervention staffs named CMIR (Mobile Units of Radiological Intervention) are equipped with instrument for external contamination monitoring [1].

Hand-held instruments are also available in many places such as hospital, laboratories and nuclear site (both civilian and military).

F2.2 Portal Monitors

A portal monitor is available at IRSN on the site of LE VESINET near Paris. It is intended to be used for fast triage before decontamination by a mobile tent unit.

F3 INTERNAL CONTAMINATION MONITORING

F3.1 Thyroid and whole body monitoring

Equipment available at the French Institute for Radiological Protection and Nuclear Safety (IRSN)

IRSN mobile body counters developed by the former French radioprotection institute SCPRI include 8 vehicles and a wagon (photo 1).

Five Master-Gemini vehicles are equipped with two GEMINI measurements units and one vehicle with one unit.

A GEMINI measurement unit consists in 2 seats. Each one is equipped with two sodium iodide detectors placed in lead collimators. The first detector, a 2’’x2’’ sodium iodide crystal, is used to detect the presence of radioisotopes in the lung. The second detector, a 1’’x1” sodium iodide crystal, is used to detect the presence of iodine in the thyroid. Resolution at 66 keV is 50 keV (7.5%). The detection limits are 500 Bq and 20 Bq for Cs-137 and I-131 respectively for 10 min counting time.

The daily counting capacity is 200 per vehicles equipped with four seats.

- A trailer-trunk equipped with six GEMINI measurements units (i.e. 12 seats) resulting to a counting capacity of 400 person/day.
- A trailer-trunk with four whole-body counter in lead shielding sarcophagus. Each shielding sarcophagus is equipped with a 3”x5”x16” sodium iodide detector. The detection limit for Cs-137 is 150 Bq for 10 min counting time. Counting capacity is 80 person/day
- A wagon equipped with 16 GEMINI measurements units (i.e. 32 seats) resulting to a counting capacity of 1280 person/day.

IRSN has recently developed a new mobile vehicle for body counting with germanium detectors dedicated to expert measurements (photos 2 and 3). The measurement station consist of two germanium detectors (s: 5000mm^2, H: 30 mm, relative efficacy: 50%, cryo-electric cooling) positioned in a lead shielded bed. Whole body, lungs and thyroid counting can be performed. Energy range is 10-2000 keV. Resolution varies from 0.5 (at 5.9 kev) to 2.2 keV (at 1332 keV). Detection Limits are 80 Bq for Cs-137 (whole body counting), 5 Bq for I-131 (thyroid counting), 15 Bq for Am-241 (lung counting). Capacity of counting is 20 persons per day for 30 mm counting time. Another similar vehicle will be acquired by IRSN in 2008.

Equipment available at the French Defence Radiation Protection Service (SPRA)

SPRA mobile body counters include two vehicles [2]:

- A vehicle with two GEMINI measurements stations (same type as that owned by IRSN).

- A vehicle equipped with a 3”x5”x16” sodium iodide detector positioned in a 450 kg lead shielding (FASTSCAN). Detection limit for Cs-137 after 10 min measurement time is 100 Bq.

Others equipment available in France

Among the fireman specialized CMIR units, four are equipped with a Master-Gemini vehicle including two GEMINI units with 4 seats able to measure thyroid and thorax contamination:

- Agen (SDIS 47),
- Avignon (SDIS 84),
- Thionville (SDIS 57),
- Lille (SDIS 59)

A mobile vehicle is also available at AREVA La Hague nuclear site in Normandy. It is equipped with two 3”x5”x16” sodium iodide detector positioned in a 1300kg lead shielding (AntARIES). Detection limit for 137 Cs after 3 min measurement time is 600 Bq.

F3.2 Mobile radiochemical measurements

Equipments available at the French Institute for Radiological Protection and Nuclear Safety (IRSN)

The new IRSN mobile vehicle for body counting is also equipped with a X/gamma spectrometry system for urine analysis. Gamma-emitters radionuclide can be identified with a Germanium BEGe detector similar to those used for anthropo-radiometric measurements. The detector is placed in a lead shielding cell.

Detection limits for Co-60, Tc-99m, I-131 and Cs-137 have been found below 1 Bq.l^{-1} for a 2 hour counting time

Equipment available at the French Defence Radiation Protection Service (SPRA)

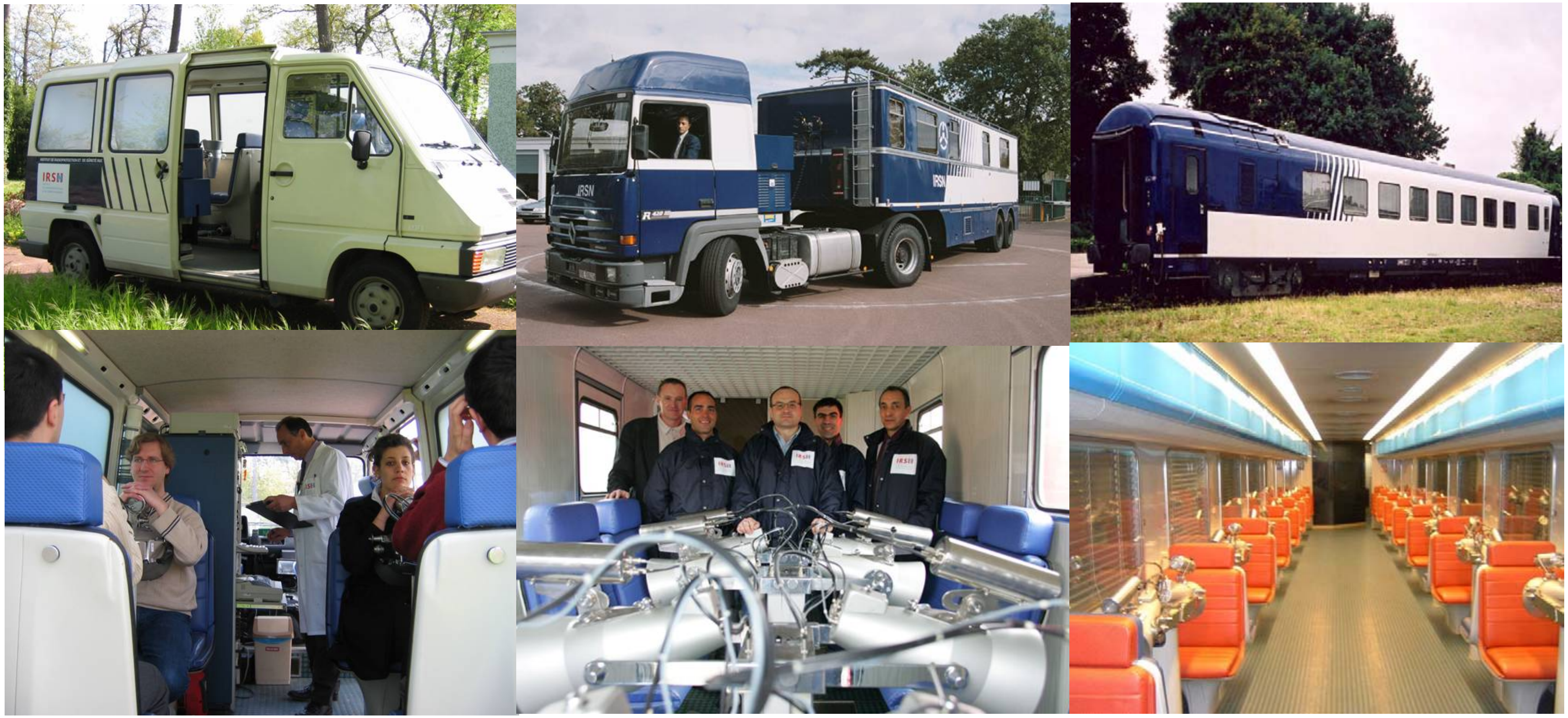
SPRA has developed a mobile laboratory for radiochemical analysis equipped with alpha, beta and gamma detection systems and for simple sample preparation. Analysis can be performed on paper hand-kerchiefs (for nose-blow samples) or urine. Alpha emitters are detected in urine by liquid scintillation counting with a detection limit of 30 Bq l^{-1}. Gamma emitters are measured with a portable high-resolution germanium detector. Twenty gamma analyses can be performed per day with a detection limit of 10 Bq l^{-1} after 1h measuring time. Tritium and other beta emitters are identified by liquid scintillation. The detection limit for beta measurements is 15 Bq l^{-1} and 10 analyses per day can be performed.

References

[1] Review of Infrastructures and Preparedness Systems in France, Germany and United Kingdom for Potential Releases of Radioactivity into the Environment. Project deliverable of the EC Project SAGE. http://www.ec-sage.net/D04_01.pdf

[2] Castagnet X., Amabile J.C., Cazoulat A., Lecompte Y., de Carbonnières H., Laroche P. Diagnosis of internal radionuclide contamination by mobile laboratories. Radiation Protection Dosimetry (2007)

Photo 1- IRSN mobile facilities equipped with GEMINI measurement stations



Master-Gemini

Truck

Wagon

Photo 2 – IRSN new mobile vehicle for body counting

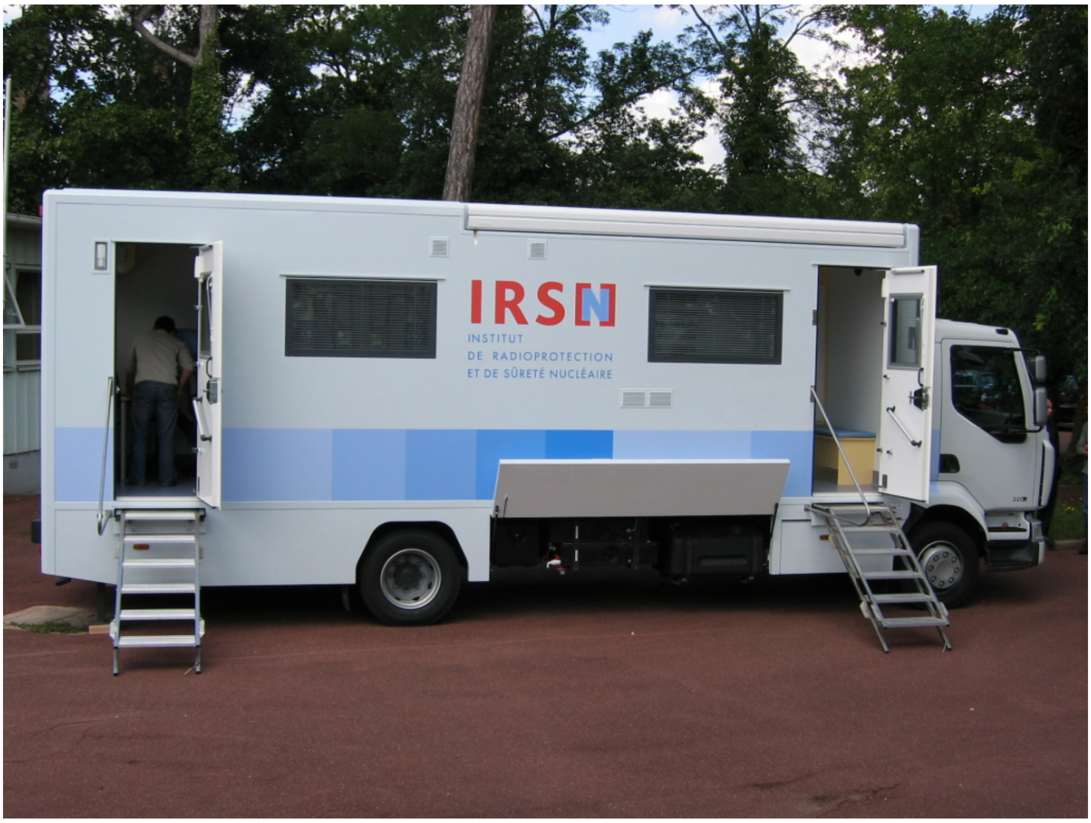
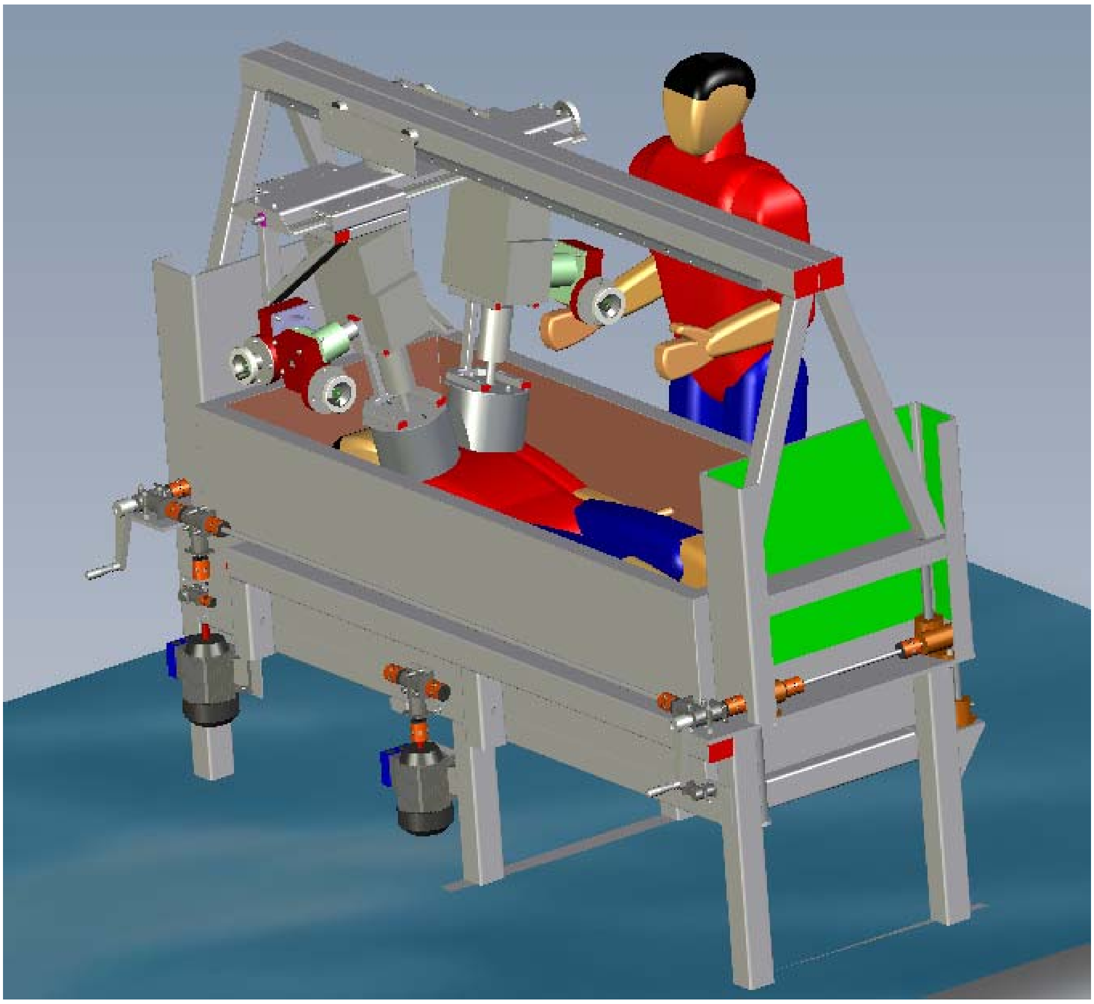


Photo 3 – Measurement station of the IRSN new mobile vehicle for body counting



APPENDIX G Portable and transportable monitoring equipment in Spain

Maria Antonia Lopez, CIEMAT (Madrid, Spain)

Jose Manuel Martin Calvarro, CSN (Madrid, Spain)

G1 INTRODUCTION

This document summarizes the portable and transportable monitoring equipment that would be available for monitoring members of the public following an accidental or deliberate release of radioactivity in Spain. It covers instruments for measurement of external and internal contamination. The information is taken from official sources of the Nuclear Safety Council (CSN), Spanish regulatory body.

The management of nuclear and radiological emergencies in Spain is coordinated by CSN. The National Emergency Plan has been designed by CSN taking into account that this country counts with 8 Nuclear Power Plants (NPPs) operating at this moment (October 2007) and one nuclear power plant is in process of dismantling. Other facilities to be considered at risk of radiological emergency situation are the ENUSA Plant for the fabrication of nuclear fuel elements and the ENRESA facility for the storage of low and medium activity wastes.

There are 5 official “Plans of Nuclear Emergency” coordinated from 5 Spanish towns close to NPPs, for the local management of nuclear emergency situations. These national Emergency plans are indicated as follows:

PENBU in Burgos (close to Santa Maria de Garoña NPP)

PENCA in Caceres (close to Almaraz I and II NPP)

PENTA in Tarragona (close to Asco I and II and Vandellos II NPPs)

PENGUA in Guadalajara (close to Trillo NPP)

PENVA in Valencia (close to Cofrentes NPP)

Other Spanish towns are also equipped to be ready as technical support (Radiological Emergency Equipment) in case of accidental or deliberate release of radioactivity to the environment: Santiago, Santander, Madrid, Granada, Córdoba and La Laguna in Canary islands.

In Madrid, the SALEM, at CSN headquarters, is a 24 h operating facility which coordinates all the management, information and actions to be carried out in case of nuclear emergency.

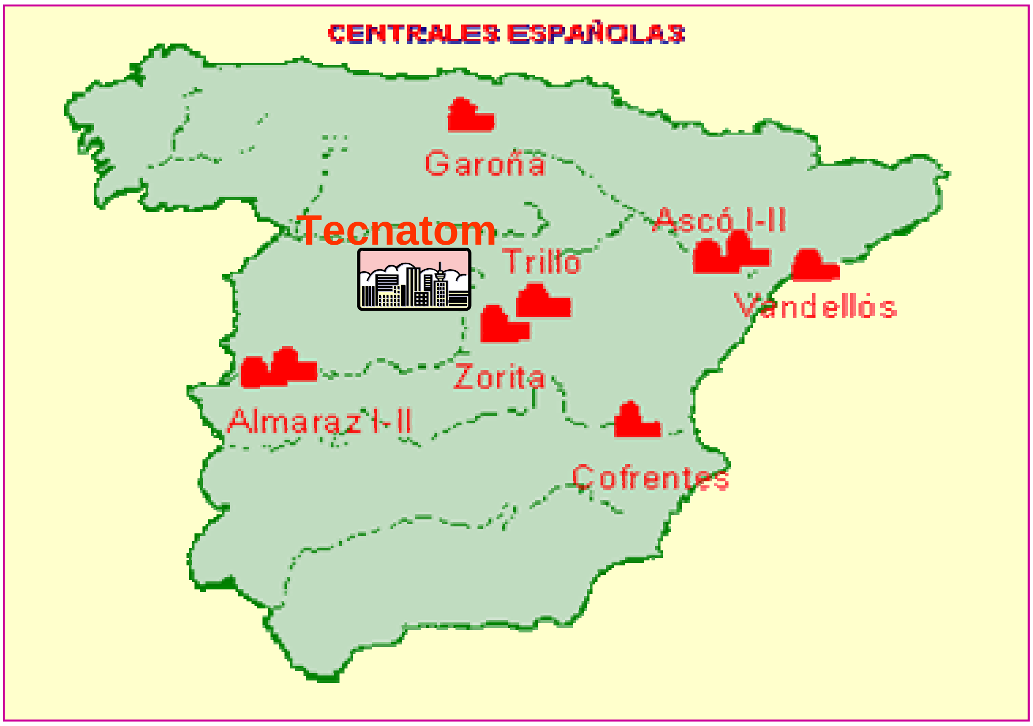


Figure 1.- Nuclear Power Plants and Tecnatom Co. in Spain

G2 EXTERNAL CONTAMINATION MONITORING

CSN has established an official agreement with the Radiation Protection Technical Unit of the company EULEN-PROINSA for the management and maintenance of equipment to be used in case of nuclear emergency. This technical support is focused in the emergency local management, as well as in the management of radiometric tools to be applied in each specific situation.

PROINSA has developed a Software (GEMINIS), with restricted web access with a password, only for CSN, where all the equipment available to be used in case of nuclear emergency is registered there. Updated information about monitors, dosimeters and other tools is collected, as well the actual status of the equipment (7000 units) in relation to location, calibration and operative features of interest. The information is provided as follows:

G2.1 Active Dosimeters (APD)

844 units distributed in locations coordinated by PENBU, PENCA PENTA, PENGUA and PENVA, also in Madrid-CSN, Madrid-SALEM, Santiago, Santander, Madrid, Granada, Córdoba and Canary islands.

Type of APD: EPDs MK2 Siemens (Electronic Personel Dosimeters, currently 2500 of this type of dosimeter are in CSN headquarter waiting to be distributed)

G2.2 Stylodosimeters

1885 units distributed in locations coordinated by PENBU, PENCA PENTA, PENGUA and PENVA

- Type of Stylodosimeter: DOSIMETER610. DOSIMETER866

G2.3 Contamination Monitors

100 units distributed in locations coordinated by PENBU, PENCA PENTA, PENGUA and PENVA, also in Madrid-CSN, Madrid-SALEM, Santiago, Santander, Madrid, Granada, Córdoba and Canary islands.

Type of Contamination Monitors: EBERLINE-CONTAMAT FHT-111M and BERTHOLDLB-1210-D

G2.4 Radiation Monitors

90 units distributed in locations coordinated by PENBU, PENCA PENTA, PENGUA and PENVA, also in Madrid-CSN, Madrid-SALEM, Santiago, Santander, Madrid, Granada, Córdoba and La Laguna in Canary islands.

Type of Radiation Monitors: **EBERLINE FH-40 and ALNOR RDS-120**

G2.5 TLDs

4000 units distributed in locations coordinated by PENBU, PENCA PENTA, PENGUA and PENVA.

Type of TLD: N.E. Technology, TLD 860/N/52

There are 24 external dosimetric services legally approved by CSN to perform the official evaluation of external doses in Spain. All these services are available in case of radiological or nuclear emergency.

G3 INTERNAL CONTAMINATION MONITORING

There are 9 internal dosimetric services legally approved by CSN to perform the official evaluation of internal doses in Spain. Eight services are dealing with exposures in (NPPs) carrying out in-vivo measurements of gamma-emitters deposited in the body.

The Internal Dosimetry of CIEMAT is the only place in Spain which performs measurements of Actinides in lungs and in bone and where bioassay determinations of the Activity in urine or/and faeces can be carried out.

In case of accidental or deliberate release of radioactivity, there is an official agreement between CSN and the internal dosimetry service of TECNATOM: two mobile units containing two whole body counting systems respectively, are available for in-vivo measurements of gamma emitters in the body. The Mobile Unit nº1 consists of a Quicky in-vivo system of 4 NaI(Tl) detectors, for a fast evaluation (T= 2 minutes) of radionuclides incorporated, using a standing-up counting geometry. The Mobile Unit nº2 is a whole body counter, with one NaI(Tl) detector, using a scanning bed counting geometry. In both cases it is also possible to evaluate exposures of ^{131}I deposited in thyroid.

APPENDIX H Portable and transportable monitoring equipment in the UK

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H1 INTRODUCTION

This document summarises the portable and transportable monitoring equipment that would be available for monitoring members of the public following an accidental or deliberate release of radioactivity. It covers instruments for measurement of external and internal contamination. Some of the information is taken from a recent survey [1] of radiological monitoring resources in England, Scotland and Wales. More than 270 organisations provided information. These were predominantly from hospitals, local government authorities, and research establishments and emergency services. It should be noted that further monitoring capability has been introduced by the emergency services to respond to a radiological terrorist incident but the details are generally restricted and were excluded from the survey. The nuclear site operators also have large numbers of instruments for monitoring. These sites will try to help with monitoring of members of the public, however operational requirements may mean they are not be able to provide staff and equipment for a particular incident.

H2 EXTERNAL CONTAMINATION MONITORING

H2.1 Hand-held instruments

In the survey, about 30% of hospitals indicated that they could attend a Radiation Monitoring Unit (RMU) and make external contamination measurements. Each hospital could potentially provide 1 or 2 teams. However, attendance of hospital staff at an RMU will depend on the need to maintain clinical services. Hospitals which could attend at a RMU, have on average 6 hand-held instruments which are suitable for beta contamination monitoring, although the range is very large (1 to more than 20). Typically the instruments available are the Thermo Mini series ratemeter 900 with EP15 or 900E probes and the Berthold LB1210 LB. There are fewer hospitals with alpha contamination equipment (about 20%) and each of these has fewer instruments for alpha contamination monitoring, on average 3 per hospital (range 1-7). Typical instruments are Thermo series 900 with AP2 probe and Berthold LB120B. Hospitals have more instruments for gamma contamination monitoring, on average 6 per hospital (range 1 to more than 20). Available instruments are frequently the Mini Instruments series 900 ratemeter with type 42 or 44 probes. Beta and gamma monitoring instruments, held by hospitals, are generally maintained and calibrated. Alpha contamination monitors are generally maintained, but relatively few are calibrated.

In addition to the instruments mentioned above, all accident and emergency departments of hospitals in England and Wales have been supplied with RAM GENE-1 monitors which are capable of both dose rate and alpha and beta contamination measurements. Some of these instruments may be deployable to an RMU if required.

Of the fire and rescue services which completed the survey, about half are able to do personal monitoring for beta and gamma contamination. The instrument generally available is the Rados RDS 200, with a suitable probe attached. Alpha contamination monitoring capability is more limited with only a few services holding suitable equipment. The fire and rescue services would not normally attend at an RMU, but have a capability to monitor people for external contamination and for decontamination of large numbers of people using purpose-built equipment.

Apart from hospitals and fire and rescue services, the only other significant contribution to facilities for external contamination monitoring would come from the nuclear site operators, the Health Protection Agency (HPA) and possibly the military. The nuclear site operators could potentially provide between 3 and 10 teams from each establishment, each equipped with suitable monitoring instruments. The HPA could provide between 2 and 4 teams from each of its three sites.

The UK nuclear site operators are well equipped with monitoring instruments. Each site has from 10 to more than100 instruments suitable for beta contamination measurements. These are typically Thermo Electra with DP2 probes and Thermo Mini series with EP15 probes. Each site can also deploy similar numbers of alpha and gamma contamination monitors. A wide range of gamma contamination instruments is available and the alpha contamination monitors are typically Thermo Electras with DP2 probes.

The Radiation Protection Division (RPD) of the HPA has approximately 30 instruments available for personal monitoring for gamma and beta contamination, split amongst 3 sites. These are typically Thermo mini 900 series ratemeters with EP15 and 900E probes, Berthold LB1210B and Electras with DP6 probes for beta contamination and Mini Instruments 900 ratemeters with type 42 and 44 probes for gamma contamination. The HPA also has about 20 instruments for alpha contamination, which are typically Berthold LB1210B and Thermo Electras with DP6 probe.

H2.2 Portal Monitors

From the results of the survey, there is no known UK capability to deploy portal monitors to the vicinity of any radiological accident or incident. However, one regional medical physics department based in northeast England has plans for one or more mobile RMUs which would be equipped with portal monitors.

H3 INTERNAL CONTAMINATION MONITORING

H3.1 Iodine in thyroid monitoring

About 25% of the hospitals surveyed can do thyroid monitoring and attend a RMU. Most of these can deploy 1 or 2 teams. Almost all of these can make measurements of both I-125 and I-131 and have calibrated and maintained detectors. Most of the detectors used are Mini Instruments 900 with type 44 probes.

A very few hospitals have hand-held NaI based gamma spectrometry instruments which could be used for iodine in thyroid measurements, but in general suitable calibrations have not been made.

The HPA has calibrated Mini Instruments 42 and 44 probes for measurements of I-125 and I-131 in the thyroid. The HPA has about 10 instruments with type 42 probes and 20 with type 44 probes. Approximate MDAs for a count of the thyroid of an adult are 2 kBq for I-131 and 400 Bq for I-125.

The only other organisations with a capability for thyroid monitoring are some of the nuclear site operators, and the military may also have a capability. Those site operators with a capability have more than 10 suitable hand-held instruments at each site, but are generally calibrated only for I-131. Two operators have gamma-spectrometry equipment which can be used for iodine in thyroid monitoring, but it is not known if this equipment is transportable.

In addition to hand-held instruments, the Radiation Protection Division (RPD) of the HPA has calibrated a Detective$^{\text{TM}}$ (Ortec, USA) high-resolution radionuclide identifier which could be used as a portable iodine in thyroid monitor and whole body monitor. This instrument is used in a similar way to that described by Kramer [2]. No shielding is used, so that the system is readily portable and can be carried by one person. The detector-to-neck distance used is 20 cm. An approximate MDA for a 5 minute count of the thyroid of an adult is 800 Bq for I-131. This MDA assumes the measurement was made in an area with no environmental contamination.

The HPA transportable in vivo monitoring system described below [3] has the capability for measuring I-131 in the thyroid. The detector is collimated to restrict the field of view, and a detector to neck distance of 10 cm. The system used a hyper-pure germanium detector (HPGe) and therefore it is possible to distinguish I-131 from the short lived radioiodine radionuclides (I-132, I-133, I-135) which would be released following a reactor accident. The system is unsuitable for measurements of other iodine radionuclides, such as I-125. An approximate MDA for a 10 minute count of the thyroid of an adult is 10 Bq for I-131.

H3.2 Whole body monitoring

The HPA has evaluated a variety of hand-held instruments which could be used for screening people, for Cs-137 internal contamination. The intention was to determine whether these instruments were sufficiently sensitive to be used to identify people who could be considered for decorporation therapy. The instruments calibrated which are available to the HPA are Mini Instruments series 900 ratemeters with type 42 and 44 probes and also Exploranium GR-130 and GR-135 instruments which are NaI(Tl) based radionuclide identifiers. The MDA for a type 44 probe is about 100 kBq for an adult.

The HPA's Detective instrument described above has also been calibrated for whole body measurements of children and adults. Again, the system is used without shielding. The person is measured in a seated position with the detector 500 mm from the chest. An approximate MDA for a 5 minute count of an adult is 6000 Bq for Cs-137. This MDA assumes the measurement was made in an area with no environmental contamination.

Approximately 10 hospitals which responded to the survey have whole body monitoring equipment based on large volume NaI(Tl) detectors. Only one of these WBMs is transportable and is based in north-east England. This system uses four 6” x 4” NaI (Tl) detectors in a bed geometry with a shadow shield arrangement. The system is mounted in a heavy goods vehicle trailer. The nuclear site operators and military are the only other organisations with whole body monitoring facilities, but none of these are transportable.

The HPA-RPD operates one transportable in vivo monitoring system [3]. This system consists of a lead shielded chair and a large volume (90% relative to a 7.62 x 7.62 cm NaI(Tl) detector) hyper-pure germanium detector (HPGe) for whole body measurements. The system also has a second HPGe detector for measurements of radioiodine in thyroid (see above). Both detectors have lead collimators approximately 3.5 cm thick. The collimator for the whole body monitoring detector restricts the field of view to the subject’s torso and upper-legs. This system has been calibrated for people of all ages.

This system is transported in two trailers which can be pulled by ordinary motor vehicles. The fully loaded weights of the two trailers are approximately 1200 kg each. The components are loaded using a pallet truck. The time required to unload and assemble the system is approximately 1 hour, for a team of four people. It is possible to assemble and operate the system in one of the trailers. An approximate MDA for a 10 minute count of an adult is 100 Bq for Cs-137.

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[1] Walker, K., Cox, D., McColl, N. and Prosser. S.L., Survey of Radiological Monitoring Resources in England, Scotland and Wales. Radiation Protection Division, Health Protection Agency, RPD-EPBS-002-2007 (Commercial Restricted).

[2] Kramer, Gary H.; Capello, Kevin; Hauck, Barry M (2005) The HML's New Field Deployable, High-Resolution Whole Body Counter. Health Physics. Operational Radiation Safety. 89(5) Supplement:S60-S68.

[3] Youngman, M.J. (2001) Transportable In Vivo Monitoring System for Accident Monitoring of Internal Contamination. http://www.hpa.org.uk/radiation/publications/w_series_reports/2002/nrpb_w12.htm

CONRAD WP5: COORDINATION OF RESEARCH ON INTERNAL DOSIMETRY

CONTENTS

4.- DISSEMINATION OF KNOWLEDGE: WEB SITES, WORKSHOPS, PUBLICATIONS, INTERCOMPARISONS, DATABASES AND TRAINING

5.- THE INTERNAL DOSIMETRY NETWORK

6.- CONCLUSIONS AND FUTURE ACTIONS

7.- APPENDIX A: CONRAD WP5 PUBLICATIONS

Maria Antonia Lopez[1] (CIEMAT, Spain)

[1] CIEMAT, Avda. Complutense, 22 - 28040 Madrid, Spain

4 DISSEMINATION OF KNOWLEDGE: WEB SITES, WORKSHOPS, PUBLICATIONS, INTERCOMPARISONS, DATABASES AND TRAINING

The main aim of the CONRAD Action is the generation of networks to promote coordination of research and dissemination of scientific knowledge in the field of radiation dosimetry.

A great effort was done by CONRAD WP5 to disseminate the achievements obtained by the different task-groups. Web sites, participation in international Workshops and Conferences, organization of intercomparisons, databases available in the web and training activities were applied for the presentation of CONRAD results at the dosimetry community.

4.1.- WEB SITES

- EURADOS Web site: www.eurados.org
- IDEAS/ENEA Web site: www,bologna.enea.it/attivita/ideas.html
  Internal Dosimetry forum. IDEAS Guidelines, IDEAS/IAEA Intercomparison on Dose Assessments, link to the ICRP INDOS, CONRAD project.
- SCK-CEN Web site: www.sckcen.be/ideas/ . IDEAS databases.

4.2.- WORKSHOPS

- **Workshop ID2006** “Internal Dosimetry of Radionuclides. Occupational, Public and Medical Exposures”, held in Montpellier (France), 2-5 October 2006.

  CONRAD sponsored the Conference. The following works were presented and published in Rad. Prot. Dosimetry (2007):

  - *Coordination of Research on Internal Dosimetry in Europe: the CONRAD Project.* M.A. Lopez et al.
  - *Monte Carlo modelling for in vivo measurements of Americium in a knee voxel phantom: general criteria for an international intercomparison.* J.M. Gómez-Ros et al.
  - *The Work of the CONRAD Task Group 5.2 "Research Studies on Biokinetic Models“.* D. Nosske et al.
  - *Evaluation of scattering factor values for the internal dose assessment following IDEAS guidelines: preliminary results*. J.W. Marsh et al.

- **Conference SSD15** “Solid State Dosimetry Conference”, Delf, The Netherlands, 8-13 July 2007 (http://www.ssd15.org). Radiation Measurements Journal (in press).
  - *Monte Carlo modelling of Germanium detectors for the measurement of low energy photons in internal dosimetry: results of an international comparison*n.
    J.M. Gómez-Ros, D. Franck et al.

- **HPS-2007** “52nd Annual Meeting of the Health Physics Society”, Portland, USA, 8-12 July 2007. Health Physics. 93(1), pp. S12, 2007.
    - *International comparison on Monte Carlo modelling for in vivo measurements of Americium in a knee voxel phantom.* J.M. Gómez-Ros, D. Franck et al.

- **CONRAD WP4 Workshop** “Uncertainty Assessment in Computational Dosimetry. A comparison of approaches”; Bologna, Italy, 8-10 October 2007.
    - *International comparison on Monte Carlo modelling for in vivo measurements of Americium in a knee voxel phantom.* J.M. Gómez-Ros, D. Franck et al.

- **AM2008 - EURADOS Annual Meeting**. Scientific Symposium “Achievements of CONRAD Project”. Paris, 21-25 January 2008.
    - *Internal Dosimetry: towards harmonisation and coordination of research.* M.A. Lopez et al.
    - *Internal Dose Assessments : Uncertainty studies and update of IDEAS Guidelines and Databases.* J.W. Marsh, C.M. Castellani, C.Hutgen et al.
    - *Development, implementation and quality assurance of biokinetic models within CONRAD.* D. Nosske et al.

- **Nordic Society for Radiation Protection.** Ålesund, Norway, May 26-30, 2008.
    - *A European network of experts directly responsible for monitoring and assessment of doses after deliberate exposure to ionizing radiation*. Tua Rahola, Maarit Muikku, Peter G D Pellow, George Etherington, Alan Hodgson, Mike J Youngman, Cécile Challeton-de Vathaire, Bernard Le Guen, Philippe Bérard and Maria Antonia Lopez

- **Conference IRPA12,** Buenos Aires, Argentina. October 2008.
    - *Characterisation, implementation and quality assurance of biokinetic models. The experience of the CONRAD Task Group 5.2.* A. Giussani, D. Nosske et al.
    - *A European network for experts with direct responsibility for monitoring and dosimetry after a deliberate release of radioactive material or a deliberate radiation exposure*. T. Rahola, G. Etherington et al.

4.3.- PUBLICATIONS

- **Radiation Measurements Journal (in press, 2008)**
  doi: http://dx.doi.org/10.1016/j.radmeas.2007.12.023

  Monte Carlo modelling of Germanium detectors for the measurement of low energy photons in internal dosimetry: results of an international comparison. J.M. Gómez-Ros, L. de Carlan, D. Franck, G. Gualdrini, M. Lis, M.A. López, M. Moraleda, M. Zankl, A. Badal, K. Capello, P. Cowan, P. Ferrari, B. Heide, J. Henniger, V. Hooley, J. hunt, S. kinase, G.H. Kramer, D. Löhnert, S. Lucas, V. Nuttens, L.W. Packer, U. Reichelt, T. Vrba, J. Sempau, B. Zhang.

- **Health Physics. 93(1), pp. S12, 2007.**
  International comparison on Monte Carlo modelling for in vivo measurements of Americium in a knee voxel phantom.
  J.M. Gómez-Ros, L. de Carlan, D. Franck, G. Gualdrini, M. Lis, M.A. López, M. Moraleda and M. Zankl.
- **Rad Prot Dosimetry, doi:10.1093/rpd/ncm350 (2007)**
  Coordination of Research on Internal Dosimetry in Europe: the CONRAD Project.
  M.A. Lopez, G. Etherington, C.M. Castellani, D. Franck, C. Hurtgen, J. Marsh, D. Nosske, H. Doerfel, A. Andrasi, M. Bailey, I. Balashazy, P. Battisti, P. Bérard, V. Berkowski, A. Birchall, E. Blanchardon, Y. Bonchuk, M. Boschung, L. de Carlan, M.C. Cantone, C. Challeton-de Vathaire, R Cruz-Suarez, K. Davis, D. Dorrian, A. Giussani, B. Le Guen, A. Hodgson, J.R. Jourdain, V. Koukouliou, A. Luciani, I. Malatova, A.Molokanov, M. Moraleda, M. Muikku, U. Oeh, M. Puncher, T. Rahola, H. Ratia, N. Stradling.

- **Rad Prot Dosimetry, doi:10.1093/rpd/ncm403 (2007)**
  Monte Carlo modelling for in vivo measurements of Americium in a knee voxel phantom: general criteria for an international intercomparison.
  J.M. Gómez-Ros, L. de Carlan, D. Franck, G. Gualdrini, M. Lis, M.A. López, M. Moraleda and M. Zankl

- **Rad Prot Dosimetry, doi:10.1093/rpd/ncm257 (2007)**
  The Work of the CONRAD Task Group 5.2 "Research Studies on Biokinetic Models".
  D. Noßke, V. Berkovski, A. Birchall, E. Blanchardon, M.C. Cantone, K. Davis, A. Giussani, A. Luciani, J. Marsh, U. Oeh, H. Ratia and M.A. Lopez.
- **Rad Prot Dosimetry, doi:10.1093/rpd/ncm353 (2007)**
  Evaluation of scattering factor values for the internal dose assessment following IDEAS guidelines: preliminary results. J.W. Marsh, A. Andrasi, M.R. Bailey, A. Birchall, E. Blanchardon, V. Berkovski, Y. Bonchug, C.M. Castellani, A. D. Desai, H. Doerfel, M-D Dorrian, C. Hurtgen, V. Koukouliou, M. A. Lopez, A. Luciani, I. Malatova, A. Molokanov, M. Puncher, H. Ratia.

- **Rad Prot Dosimetry (2008)**
  Internal Dosimetry: towards harmonisation and coordination of research.
  M.A. Lopez, G. Etherington, C.M. Castellani, D. Franck, C. Hurtgen, J.W. Marsh, D. Nosske, B. Breustedt, E. Blanchardon, A. Andrasi, M. Bailey, I. Balashazy, P. Battisti, P. Bérard, A. Birchall, D. Broggio, C. Challeton-de-Vathaire, R Cruz-Suarez, H. Doerfel, A. Giussani, A. Hodgson, V. Koukouliou, G.H. Kramer, B. Le Guen, A. Luciani, I. Malatova, A. Molokanov, M. Moraleda, M. Muikku, U. Oeh, M. Puncher, T. Rahola, N. Stradling, T. Vrba

- **Rad Prot Dosimetry (2008)**
  Development, implementation and quality assurance of biokinetic models within CONRAD
  D. Noßke, A. Birchall, E. Blanchardon, B. Breustedt, A. Giussani, A. Luciani, U. Oeh and M.A. Lopez
- **Rad Prot Dosimetry (2008)**
  Internal Dose Assessments: Uncertainty studies and update of IDEAS Guidelines and Databases within CONRAD Project. J. W. Marsh, C.M. Castellani, C. Hurtgen, A. Andrasi, M.R. Bailey, A. Birchall, E. Blanchardon, A. D. Desai, M-D Dorrian, H. Doerfel, V. Koukouliou, M. A. Lopez, A. Luciani, I. Malatova, A. Molokanov, M. Puncher, T. Vrba
- **Rad Prot Dosimetry (2008)**
  Analysis of Computational Problems involving complex voxel geometries.

J.M. Gómez-Ros, L. de Carlan, D. Franck, G. Gualdrini, M. Lis, M.A. López, M. Moraleda and M. Zankl.

- **Workshop "Uncertainty Assessment in Computational Dosimetry. A comparison of approaches" Proceedings (2007).**

  International comparison on Monte Carlo modelling for in vivo measurements of Americium in a knee voxel phantom. J.M. Gómez-Ros, L. de Carlan, D. Franck, G. Gualdrini, M. Lis, M.A. López, M. Moraleda, M. Zankl, A. Badal, K. Capello, P. Cowan, P. Ferrari, B. Heide, J. Henniger, V. Hooley, J. hunt, S. kinase, G.H. Kramer, D. Löhnert, S. Lucas, V. Nuttens, L.W. Packer, U. Reichelt, T. Vrba, J. Sempau, B. Zhang.

- **Conference IRPA12, Proceedings (2008).**

  Characterisation, implementation and quality assurance of biokinetic models. The experience of the CONRAD Task Group 5.2. A. Giussani, D. Nosske , A. Birchall, E. Blanchardon, B. Breustedt, A. Luciani, J. Marsh, U. Oeh, H. Ratia, M.A. Lopez

- **IRPA12, Proceedings (2008).**

  A European network for experts with direct responsibility for monitoring and dosimetry after a deliberate release of radioactive material or a deliberate radiation exposure.
  T. Rahola, M. Muikku, P.G.D. Pellow, G. Etherington, A. Hodgson, M.J. Youngman, C. Challeton-de Vathaire, B. Le Guen, P. Bérard and M.A. Lopez.

4.4.- INTERCOMPARISONS

- "**Intercomparison on Monte Carlo modelling for in vivo measurements of Americium in a knee phantom".** Joint CONRAD WP5+WP4 collaboration.
- **"Intercomparison on in-vivo measurements and Monte Carlo modelling of Americium in a DOE leg phantom".** Joint CONRAD+DOE collaboration.

4.5.- DATABASES

- **IDEAS Internal Contamination Database**: compilation of published internal contamination cases which include monitoring data suitable for assessment.
- **IDEAS Bibliographic Database**: was set up with references to papers in the open literature dealing with problems related to cases of internal contamination.
- **IDEAS Evaluation of Cases Database**: contains a summary of information about the evaluations.

As the CONRAD project proceeded, the first two databases were updated with new input; all three IDEAS databases are made available to the internal dosimetry community by setting them for download on a webpage named IDEAS Databases hosted at the SCK•CEN website.

4.6.- TRAINING

- **1st EURADOS Winter School.** AM2007, Madrid, Spain. January 2007.

  James Marsh (HPA, UK) and **Alan Birchall** (HPA, UK).

  Tutorial on uncertainties in internal dosimetry.
  - Scattering factors
  - Autocorrelation methodology

- **EURADOS/IAEA Training Course on Internal Dosimetry "Application of IDEAS Guidelines and dissemination of CONRAD WP5 results",** to be celebrated at **University of Prague (Czech Republic), 2-6 February 2009.**

  Coordinator: C.M. Castellani (ENEA, Italy)

  Objectives:

  - To present and to promote the use of IDEAS guidelines mainly for personnel already familiar with internal dosimetry matters.
  - Let the participants to be able to practice on internal dose assessement following the IDEAS guidelines.
  - Have some demonstrations of available software to perform advanced dose assessement.
  - Present the results of the various tasks of WP5 of the CONRAD project.

5 THE INTERNAL DOSIMETRY NETWORK

The Internal Dosimetry Network includes 40 members, distributed as follows:

AEKI (Hungary):	Andor Andrasi (T5.1, T5.5)
	Imre Balashazy (T5.2)
BfS (Germany):	Dietmar Nosske (T5.2)
CEA (France):	Philippe Bérard (T5.4)
CIEMAT (Spain):	María Antonia Lopez (Chairperson, T5.3)
	Montse Moraleda (T5.3)
EDF (France):	Bernard Le Guen (T5.4)
ENEA (Italy):	Carlo Maria Castellani (T5.1, T5.2)
	Andrea Luciani (T5.1, T5.2)
	Paolo Battisti (T5.4)
FZK Karlsruhe (Germany):	Bastian Breustedt (T5.2)
GAEC (Greece):	Virginia Koukouliou (T5.1)
GsF (Germany):	Uwe Oeh (T5.2)
	Augusto Guissani (T5.2)
HML (Canada):	Gary H. Kramer (T5.3)
HPA (UK):	George Etherington (Secretary, T5.4, T5.1)
	James Marsh (T5.1, T5.2, T5.5)
	Alan Birchall (T5.1, T5.2)
	Mike Bailey (T5.1, T5.2, T5.5)
	Neil Stradling /Alan Hodgson (T5.4)
	Martin Puncher (T5.1, T5.2)
IAEA:	Rodolfo Cruz
	Christian Schmitzer
INFO-System (Germany):	Hans Doerfel (T5.1)
IRSN (France):	Didier Franck (T5.3)
	David Broggio (T5.3)
	Eric Blanchardon (T5.1, T5.2)
	Andrey Molokanov (T5.1, T5.2)
	Cécile Challeton-de-Vathaire (T5.4)
	Jean-René Jourdain (T5.2)
NRPI (Czech Rep.):	Irena Malatova (T5.1)
RPI (Ukraine):	Vladimir Berkowski / B. Yuri / H. Ratia (T5.1, T5.2)
SCK-CEN (Belgium):	Christian Hurtgen (T5.1, T5.5)
STUK (Finland):	Tua Rahola (T5.4)
	Maarit Muikku (T5.4)
Univ. of Milan (Italy):	Marie Claire Cantone (T5.2)
Univ. of Prague (Czech Rep.):	Tomas Vrba (T5.1, T5.2, T5.3)

INTERNAL DOSIMETRY NETWORK: 20 Institutes, 14 countries

- ✓ **AEKI (Hungary)**
- ✓ **BfS (Germany)**
- ✓ **CEA (France)**
- ✓ **CIEMAT (Spain)**
- ✓ **EDF (France)**
- ✓ **ENEA (Italy)**
- ✓ **FZK Karlsruhe (Germany)**
- ✓ **GAEC (Greece)**
- ✓ **Hermann-von Hellmoltz (Germany)**
- ✓ **HML (Canada)**
- ✓ **HPA (UK)**
- ✓ **IAEA (Austria)**
- ✓ **Info System (Germany)**
- ✓ **IRSN (France)**
- ✓ **NRPI (Czech Rep.)**
- ✓ **RPI-Kiev (Ukraine)**
- ✓ **SCK-CEN (Belgium)**
- ✓ **STUK (Finland)**
- ✓ **Univ. Milan (Italy)**
- ✓ **Univ. Prague (Czech Rep.)**

The CONRAD WP5 network established **links and collaboration with other groups or institutions,** to develop some specific tasks:

- ◆ **CONRAD WP4 “Computational Dosimetry”** – Monte Carlo (MC) Intercomparison
- ◆ **ICRP Committee 2 (INDOS, DOCAL)** – Biokinetic Models
- ◆ **IAEA –** Training Course on Internal Dosimetry
- ◆ **DOE (U.S.A.)** – In-vivo monitoring + MC Intercomparison
- ◆ **TIARA Project (EC) –** Nuclear Emergency, DTPA Model
- ◆ **TMT Handbook Project (EC)** – Nuclear Emergency
- ◆ **CEA (France)** – DTPA-Therapy Dosimetric Model
- ◆ **ISO WG13** – Uncertainties on dose assessment

INTERNAL DOSIMETRY NETWORK: The information associated with the members of the Network is presented as follows.

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Dr.	Doerfel	Hans	IDEA System GmbH		Am Burgweg 4	76227	Karlsruhe	+49 721 9415374	+49 721 9415373	info@idea-system.com
Dr.	Cruz Suáres	Rodolfo	International Atomic Energy Agency		Wagramerstrasse 5, P.O.Box 100	A-1400	Vienna	+43 1 2600 22713	+43 1 26007 22723	r.cruz-suarez@iaea.org
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	Yuri	Bonchuk	Institute of Radiation Protection		Melnikova 53	4050	Kiev			Bonchuk@rpi.kiev.ua

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			Commission							
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	Oeh	Uwe	Forschungszentrum für Umwelt und Gesundheit, GSF	Institut für Strahlenschutz	Ingolstaedter Landstraße 1	85764	Neuherberg	+49-(0)89-3187-4247	+49-(0)89-3187-2517	uwe.oeh@gsf.de
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6 CONCLUSIONS AND FUTURE ACTIONS

The work developed by CONRAD Work package 5 was focused on the coordination of research in the field of internal dose assessments, and promoted the generation of an internal dosimetry network and the dissemination of scientific knowledge.

The results of this action have contributed to a more harmonised and reliable evaluation of intakes and doses due to the radionuclides incorporated in the human body. Different work areas were considered, such as uncertainty analysis, improvement of IDEAS Guidelines, implementation of last biokinetic models, development of the first DTPA-therapy model, application of new tools like Monte Carlo methods and voxel phantoms and the generation of EUREMON Network for Monitoring in case of Nuclear Emergency. All these tasks proposed were successfully achieved.

Future actions of the group will be developed within the “EURADOS Working Group 7-Internal Dosimetry” (WG7). First objective of this group from now on is the **Maintenance of the Internal Dosimetry Network** and to continue with **coordinated research actions** beyond CONRAD. Some tasks are already been defined:

- *Implementation and quality assurance of biokinetic models*
- *The Development of the DTPA-Therapy Dosimetric Model*
- *In-vivo monitoring + Monte Carlo Modeling intercomparisons*
- *Collaboration with TMT-Handbook Project (VI FP) – Monitoring in Nuclear Emergency*

The **Dissemination of scientific knowledge** through publications, workshops, websites, training activities,… is also an important priority of EURADOS WG7.

7 APPENDIX A: CONRAD WP5 PUBLICATIONS

Radiation Protection Dosimetry (year), Vol. 0, No. 0, pp. 0–0
DOI: 10.1093/rpd/nc0000

Proposed for RPD Publication, special issue – EURADOS AM2008

INTERNAL DOSIMETRY: TOWARDS HARMONISATION AND COORDINATION OF RESEARCH

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CONRAD Project is a Coordinated Network for Radiation Dosimetry funded by the European Commission 6th Framework Programme. The activities developed within CONRAD Work Package 5 ("Coordination of Research on Internal Dosimetry") have contributed to improve the harmonisation and reliability in the assessment of internal doses. The tasks carried out included a study of uncertainties and the refinement of the IDEAS Guidelines associated with the evaluation of doses after intakes of radionuclides. The implementation and quality assurance of new biokinetic models for dose assessment and the first attempt to develop a dosimetric model for DTPA therapy are important WP5 achievements. Applications of voxel phantoms and Monte Carlo simulations for the assessment of intakes from in vivo measurements were also considered. A Nuclear Emergency Monitoring Network (EUREMON) has been established for the interpretation of monitoring data after accidental or deliberate releases of radionuclides. Finally, WP5 group has worked on the update of the existing IDEAS bibliographic, internal contamination and case evaluation databases. Some WP5 tasks were linked with ICRP activities; a joint-action was established with CONRAD Work Package 4 "Computational Dosimetry" and collaborations with other EC research projects (TMT-handbook, Tiara) and with relevant institutions such as DOE (USA) and CEA (France) were carried out for some specific works. An internal dosimetry network was generated to facilitate exchange of knowledge and coordination of the research. A summary of CONRAD WP5 objectives and results is presented here.

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INTRODUCTION

Internal Dosimetry embodies always a challenge. Internal doses can not be measured directly, each chemical compound behaves differently inside the body, the distribution of the activity in is highly inhomogeneous, and doses are prolonged in time.

The last EURADOS study on individual monitoring for internal exposures in Europe(1) and recent international intercomparisons on dose assessments(2) have revealed that different laboratories can obtain different estimates of intakes and doses when provided with the same monitoring data. The harmonization in the implementation of adequate internal dose assessment criteria and methodology is an important goal to achieve.

Doses from intakes of radionuclides must be assessed from monitoring data using direct (whole/partial body counting) or indirect techniques (in-vitro methods and PAS/SAS). The assessment of internal doses requires (1) the application of biokinetic models (describing the metabolic behaviour of the radionuclide inside the body) and (2) input parameters such as time and route of intake and material properties (size of particles, absorption type). Even if all this information is correct the result of the assessment of the committed effective dose E(50) as a consequence of an internal exposure, depends on the skill of the assessor and the hardware/software tools available.

IDEAS Guidelines(3) were developed to provide a standard assessment of intakes and internal doses from individual monitoring data. The aim of this methodology is to guarantee a harmonised evaluation of internal exposures, in such way that two assessors following guidelines would obtain the same estimate of dose from an individual monitoring dataset, and the “best estimate” of E(50) is achieved.

IDEAS Guidelines were generated in collaboration with Committee 2 of the International Commission on Radiological Protection (ICRP). ICRP provides and regularly updates the biokinetic models, retention and excretion functions and dose coefficients needed for the evaluation of intakes and doses from monitoring data.

On other hand, Working Group 13 of the International Standardisation Organisation (ISO) has made a great effort to standardise the monitoring of workers (ISO20553:2006)(4) and the dose assessment (ISO27048)(5) in case of risk of internal contamination with radioactive material.

The scenario presented above was the framework to develop an international action towards harmonisation and coordination of research on internal dosimetry. This area of radiation dosimetry is a highly specialized undertaking involving physicists at various European institutions. Progress is made more efficient by active cooperation between scientists working in the field.

The Coordination Action CONRAD (Coordinated Network for Radiation Dosimetry) has been funded by the European Commission (EC) within the 6th Framework Programme (2005-2008) for research and training in nuclear energy (Contract No FI6R-012684). The objective of CONRAD is to generate a European Network in the field of Radiation Dosimetry, to promote both, research activities and dissemination of knowledge.

COORDINATION OF RESEARCH ON INTERNAL DOSIMETRY

Work package 5 (WP5)(6) within CONRAD Project dealt with the Coordination of Research on Internal Dosimetry. The research to be coordinated had as general objective to improve the reliability in the assessment of exposures resulting from the intake of radionuclides into the body. Twenty institutes from 14 countries are involved in WP5, and CIEMAT (Spain) chaired the group. Main objectives and results of WP5 tasks are presented as follows.

A. Uncertainty studies and update of IDEAS Guidelines and Databases within CONRAD(7) (8)

These tasks were coordinated by HPA (UK), ENEA (Italy) and SCK-CEN (Belgium).

Scattering Factors (SF) are used to characterise the uncertainty of measurements used in the evaluation of intakes and internal doses. The values provided by IDEAS Guidelines (5th FP, EC) were mainly defined by expert’s judgement. Calculations of SFs were carried out within CONRAD, for different radionuclides and types of monitoring data, using real cases selected from IDEAS Databases. Calculated values were in general in agreement with previous SF data suggested by IDEAS Guidelines (GLs); only SF for faecal excretion are at the lower end of the range recommended by IDEAS. The results of Scattering Factors (James et al, 2007, 2008)(7)(8) will be implemented in international standards and reference documents, leading to a harmonized assessment of uncertainties associated to intakes and internal doses.

Software was developed for the analysis study of uncertainties involved in the evaluation of internal doses. IRSN frequentist (classical) approach and HPA Bayesian approach were considered and applied to the

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case of inhalation of tritiated water (HTO)(7). Intake pattern assumptions were evaluated in the HTO case, comparing (1) ICRP recommendation of intake occurring at the mid-point of the monitoring period and (2) assumption of constant chronic intake throughout the monitoring interval.

The conclusions of the Scattering Factor study will improve IDEAS Guidelines (GLs) in some specific cases. The implementation of the new NCRP wound model and the use of a partitioning factor of the activity between skeleton and liver to be used in fitting systemic model parameters for actinides, will also be included in the revision of GLs. Evaluations of wound contamination have been done with the application of IDEAS GLs philosophy(7).

Other tasks performed by the IDEAS group within CONRAD were the evaluation of an effective AMAD and the criteria suggested to be applied (number and type of monitoring data) as requirements for internal dose assessments(7).

The IDEAS/ENEA web site (www.bologna.enea.it/attivita/ideas.html) replaced the former IDEAS web page. The results of the IDEAS/IAEA Intercomparison exercise on Internal Dose Assessments can be downloaded from this site, as well as other important reports and documents related to IDEAS, CONRAD and ICRP activities.

An important objective of WP5 was the update of IDEAS internal contamination databases(7)(9) with new cases. The IDEAS Bibliography Database contains a collection of publications with information on cases of internal contamination from which intake and committed doses could be assessed. The IDEAS Internal Contamination Database consists of published internal contamination cases with monitoring data suitable for dose assessment; IDEAS guidelines were applicable to a wide range of practical situations. The "Evaluation of Cases Database" contains a summary of information about the evaluations of some 47 cases taken out of the previous database. As the CONRAD project proceeded, IDEAS Bibliography and IDEAS Internal Contamination Databases were updated with new inputs. All three IDEAS databases are now available to the internal dosimetry community on SCK·CEN website (www.sckcen.be/ideas/) and IDEAS/ENEA webpage.

B. Developement, implementation and Quality Assurance of biokinetic models(10) (11)

This task was coordinated by BfS (Germany).

Internal doses are estimated from measured quantities that are converted to doses using complex biokinetic and dosimetric models. ICRP has published documents seeking to establish standardized biokinetics for selected radionuclides. The impact of the application of new biokinetic models for internal dose assessment was evaluated within CONRAD.

The implementation of Human Alimentary Tract Model, NCRP Wound Model and systemic models, including Quality Assurance (QA) of computational results and model formulation were important goals of this task (Nosske et al, 2008)(10).

With reference to the implementation of the new ICRP Human Alimentary Tract Model (HATM, ICRP100) an intercomparison of number of transformations and faecal excretion rates of various radionuclides including daughter nuclides as well as retention in the walls of the tract and absorption from different sites was proposed and implemented into 6 codes(10) (11). The implementation of HATM was succesful, showing an excellent agreement in the computational results obtained by the 6 European institutions.

The new NCRP Wound model (likely future ICRP Wound Model) was implemented into 6 codes for QA calculations(10); the 7 default categories of wound retention were considered for different isotopes from short-lived radionuclides (^{131}I) to long-lived radionuclides (^{239}Pu). The results showed a good agreement, especially for Plutonium.

Concerning the studies of Systemic Models, a comparison of three systemic Plutonium models was carried out by calculating the numbers of nuclear transformations for the ICRP 67 model, the Leggett 2005 model and the Luciani (age-dependent) model(10). In the application of biokinetic models for Plutonium and other actinides, the partitioning factor was evaluated as a tuning parameter to characterise the partitioning between liver and skeleton(10).

The implementation of the new ICRP Polonium model by Leggett and Eckerman was also considered(10), due to the interest caused by the incorporation incident in UK (London) and Germany (Hambourg).

A relevant and successful activity included in this work area is the experimental studies with stable isotopes carried out by Helmholtz Zentrum München, in collaboration with the University of Milan. Isotopes of Sr, Mo, Zr, Ru, and Ce were administered intravenously and orally to volunteers. Results of absorption to HAT, blood clearance and urinary excretion were analysed(10).

Results of this task are important as a support for on-going efforts of the DOCAL Group of ICRP Committee 2.

CONRAD DTPA-Therapy Model

This task was coordinated by FZK Karlsruhe (Germany) and IRSN (France).

When a severe internal exposure occurs, in some special cases chelating agents can be administered to population as therapy to increase decorporation of the incorporated radionuclides. At this time Diethylene-Triamine-Penta-Acetic Acid (DTPA) is the only chelating agent which can be administered to humans as therapy to increase decorporation of plutonium, americium and curium, thus, to reduce the internal dose.

The development of a preliminary model considering the effects of DTPA treatment was the main aim of this task(10). A reliable modelling decorporation is needed for the interpretation of bioassay data using the best physiologic models to describe the systemic behaviour of internal contaminants as Plutonium (Pu) inside the body.

The objective to achieve was a proposal of a model structure, with initial parameters for the implementation of the model(10). The test of the proposed model with real data and iterative improvement of the model are current steps to carry out. International collaboration outside CONRAD was established with experts from CEA (France) and FZK-Karlsruhe (Germany), also involved in DTPA research studies. This important task will continue in the future.

C. Application of Monte Carlo Methods and Voxel Phantoms to In-vivo monitopring of radionucleides

This task was coordinated by IRSN (France).

Series of highly detailed mathematical anthropomorphic voxel phantoms are constructed taken directly from CT or NMR images. The voxel phantoms and Monte Carlo methods can be applied to simulate in-vivo monitoring of radionuclides deposited inside the body.

The new developments in the use of voxel phantoms and Monte Carlo (MC) applications for assessment of intakes from in-vivo measurements have been evaluated within CONRAD, as a joint WP5-WP4 collaboration. The "Intercomparison on Monte Carlo modelling for in vivo measurements of Americium in a knee phantom"(12)(13)(14) was organized by CIEMAT and IRSN, and the results were presented at the Workshop "Uncertainty Assessment in Computational Dosimetry. A comparison of approaches" organised by ENEA, in Bologna, in October 2008.

A voxel phantom was generated at CIEMAT from the CT-images of a real knee phantom used for calibration purposes. A counting geometry using 2 LE Ge detectors was proposed. The exercise was distributed by e-mail to the laboratories. Counting efficiency results obtained by Monte Carlo simulations by the 13 participants of the Intercomparison were very close to the experimental efficiency value for ^{241}Am (using photopeak of 59.5 keV) obtained through the measurement of the active Spitz calibration knee-phantom at the CIEMAT Whole Body Counting facility.

The objective of the intercomparison was to confirm MC methods and voxel phantoms as valuable tools for the calculation of in-vivo calibration factors for whole body counting systems, to be applied for the assessment of intakes and internal doses. The comparison of MC codes and the evaluation of the capability of laboratories to deal with such type of exercises were also analysed.

In this framework a joint action has been established with DOE (Department of Energy, USA) to collaborate for an in-vivo monitoring and MC modelling exercise for the determination of the ^{241}Am deposited in the USTUR (United States Transuranium and Uranium Registry) knee phantom, containing real contaminated bone from a real internal contamination.

A protocol has been proposed, and a small group of selected laboratories from Europe (CIEMAT, IRSN, Helmholtz Zentrum München) and America (HML-Canada, PNL-USA) participated in the exercise. The studies to focus on are: (1) the efficiency pattern along the leg phantom (experimental and computational) and (2) the influence of Americium distribution in the bone material (volume or surface). This action is not finished yet and the results will be published in the future.

D. EUREMON: European Emergengy Network on Monitoring(15)

The death of Alexander Litvinenko in November 2006 from lethal intake of ^{210}Po, and the risk that members of the public might have been exposed to radiation was an unprecedented event in Europe. An important task dealing with the interpretation of monitoring data for emergency workers after accidental or deliberate releases of radionuclides was carried out within CONRAD. A European Emergency Network (EUREMON) has been established, to coordinate procedures and methodologies to be applied for the interpretation of monitoring data for emergency workers after accidental or deliberate releases of radionuclides (e.g. nuclear terrorism).

The aims of this monitoring in emergency task were (a) the development of a network of people with responsibilities for emergency monitoring of people; (b) sharing of information on monitoring and dose assessment procedures; (c) sharing of information on research and development (R&D); (d) coordination of this work; and (e) definition of needs for research, advice and training.

The focus of this group was the establishment of the EUREMON Network(15) (EURopean Emergency MONitoring network). Fifty European state members from 21 EU countries, 9 non-EU states and IAEA participate in the Network.

The compilation of information was carried out through the distribution of the questionnaire "Monitoring, Management and treatment of members of the public and emergency workers after accidental or deliberate releases of radionuclides or exposure to radiation". The questionnaire was prepared in collaboration with EC 6FP project TMT HANDBOOK. The objective was collecting relevant information of interest concerning organisations, legislation, monitoring strategies, equipments and facilities for individual monitoring, medical management, dose assessment methodologies and available software in case of emergency situations with release of radioactive material. The EUREMON Access Database was constructed with all the data collected.

An important activity of this task-group was the compilation of information about portable and transportable monitoring equipment available at each European state in case of nuclear emergency situation. This information could be used by countries requiring assistance in responding to a nuclear emergency. The compilation will be published together with contact details for requests for assistance.

DISSEMINATION OF KNOWLEDGE WITHIN CONRAD

The main aim of the CONRAD Action is the generation of networks to promote coordination of research and dissemination of scientific knowledge in the field of radiation dosimetry.

A great effort was done by CONRAD WP5 to disseminate the achievements obtained by the different task-groups. Web sites, participation in international Workshops and Conferences, organization of intercomparisons, databases available in the web and training activities were applied for the presentation of CONRAD results at the dosimetry community.

A Training Course on "Application of IDEAS Guidelines and dissemination of CONRAD results" will be organized at the end of CONRAD Project as a joint EURADOS-IAEA action by February 2009.

INTERNAL DOSIMETRY NETWORK

The Internal Dosimetry Network includes 40 members, from 20 Institutes of 14 countries:

- AEKI (Hungary)
- BfS (Germany)
- CEA (France)
- CIEMAT (Spain)
- EDF (France)
- ENEA (Italy)
- FZK Karlsruhe (Germany)
- GAEC (Greece)
- Hermann-von Hellmoltz (Germany)
- HML (Canada)
- HPA (UK)
- IAEA (Austria)
- Info System (Germany)
- IRSN (France)
- NRPI (Czech Rep.)
- RPI-Kiev (Ukraine)
- SCK-CEN (Belgium)
- STUK (Finland)
- Univ. Milan (Italy)
- Univ. Prague (Czech Rep.)

The network contains a good balance of senior and young researchers, facilitating the entry of young dosimetrists into the scientific community.

The CONRAD WP5 network established links and collaboration with other groups or institutions, to develop some specific tasks:

- CONRAD WP4 "Computational Dosimetry": Monte Carlo Intercomparison for in-vivo monitoring
- ICRP Committee 2 (DOCAL): Quality Assurance in the implementation of biokinetic models
- IAEA: Training Course on Internal Dosimetry
- DOE (U.S.A.): Intercomparison on in-vivo monitoring and MC simulation of Am in a USTUR leg phantom
- TIARA Project (EC): Monitoring in case of Nuclear Emergency, DTPA-Therapy Dosimetric Model
- TMT Handbook Project (EC): Monitoring in case of Nuclear Emergency

- CEA (France*)*: DTPA-Therapy Dosimetric Model
- ISO WG13: Uncertainties on dose assessment

CONCLUSIONS

The work developed by CONRAD Work package 5 was focused on the coordination of research in the field of internal dose assessments, and promoted the generation of an internal dosimetry network and the disseminaton of scientific knowledge. The results of this action have contributed to a more harmonised and reliable evaluation of intakes and doses due to the radionuclides incorporated in the human body. Different work areas were considered, such as uncertainty analysis, improvement of IDEAS Guidelines, implementation of last biokinetic models, development of the first DTPA-therapy model, application of new tools like Monte Carlo methods and voxel phantoms and the generation of EUREMON Network for Monitoring in case of Nuclear Emergency. All these tasks proposed were successfully achieved.

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COORDINATION OF RESEARCH ON INTERNAL DOSIMETRY IN EUROPE: THE CONRAD PROJECT

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The EUropean RAdiation DOSimetry Group (EURADOS) initiated in 2005 the CONRAD Project, a Coordinated Network for Radiation Dosimetry funded by the European Commission (EC), within the 6th Framework Programme (FP). The main purpose of CONRAD is to generate a European Network in the field of Radiation Dosimetry and to promote both research activities and dissemination of knowledge. The objective of CONRAD Work Package 5 (WP5) is the coordination of research on assessment and evaluation of internal exposures. Nineteen institutes from 14 countries participate in this action. Some of the activities to be developed are continuations of former European projects supported by the EC in the 5th FP (OMINEX and IDEAS). Other tasks are linked with ICRP activities, and there are new actions never considered before. A collaboration is established with CONRAD Work Package 4, dealing with Computational Dosimetry, to organise an intercomparison on Monte Carlo modelling for *in vivo* measurements of ^{241}Am deposited in a knee phantom. Preliminary results associated with CONRAD WP5 tasks are presented here.

INTRODUCTION

The Coordination Action CONRAD (Coordinated Network for Radiation Dosimetry), supported by the EC (6th FP) for research and training in nuclear energy (Contract No. FI6R-012684), was initiated in January 2005. The partners of the project are EURADOS (EUropean RAdiation DOSimetry Group), TU Delft (The Netherlands) and University of St. Gallen (Switzerland). The objectives of this action are the analysis of the options for sustainable networks linking research actors and end users, and to coordinate research into measurements and calculations for radiation protection at workplaces. To

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achieve the stated objectives, seven work packages (WP) are carried out.

The aim of CONRAD Work Package 5 (WP5) is the coordination of research and the dissemination of knowledge in the field of internal dosimetry. The research to be coordinated will improve the reliability in the assessment of internal doses. Thirty-two scientists (15 full CONRAD members and 17 corresponding members) from 18 institutes and 11 countries participate in this working group; CIEMAT (Spain) is the institution chairing this action. The tasks to be developed include a study of uncertainties associated with the assessment of doses after intake of radionuclides and the refinement of the IDEAS(1) general guidelines for internal dose evaluation after first application by internal dosimetry services. The impact of the use of new biokinetic models for dose assessment is to be evaluated, focusing initially on the new ICRP human alimentary tract model (HATM). New developments in the generation of voxel phantoms and Monte Carlo (MC) simulations for assessment of intakes from *in vivo* measurements are also to be considered. An Emergency Network is planned to be established, to coordinate procedures and methodologies to be applied for the interpretation of monitoring data for emergency workers after accidental or deliberate releases of radionuclides (e.g. nuclear terrorism). Finally, WP5 has been working on the maintenance of the existing IDEAS bibliographic, internal contamination and case evaluation databases(2). The EURADOS/CONRAD WP5 web site (www.eurados.org) summarises the objectives and activities proposed in this action and includes the links of ENEA/Ideas and SCK/Ideas web pages.

Assessment of internal exposures: uncertainty studies and refinement of IDEAS Guidelines

This Task of CONRAD WP5 is coordinated by HPA (UK) and ENEA (Italy) and has as main objective to improve the assessment of realistic uncertainties associated with the evaluation of the intake and the dose, focusing on the application of the IDEAS Guidelines. Software has been developed at HPA, IRSN, RPI Kiev and IBPh Moscow to enable uncertainty analyses using MC simulations. Probability distributions are assigned to those parameters that most affect the assessed dose and possible correlations between parameter values are considered. One of the software codes being developed estimates the probability distribution of an individual's dose *conditional* on *observed* monitoring data(3). In this case, Bayesian inference methods are used to estimate the uncertainty on the estimated dose.

Generally, a log-normal distribution with a given geometric standard deviation is used to describe the distribution of measurements performed to evaluate internal exposures. Furthermore, according to IDEAS Guidelines the overall uncertainty of an individual monitoring value can also be described in terms of a log-normal distribution and the scattering factor (SF) is defined as the geometric standard deviation; this approach is valid when Type A uncertainty (counting statistic) is small ($<30\%$). A procedure was developed(4) to evaluate, mathematically, SF values for different radionuclides and types of monitoring data using real data contained in the IDEAS Internal Contamination Database(2). Preliminary results show that the SF values are broadly in agreement with the values suggested in the IDEAS Guidelines, which were based mainly on expert judgement. However, the SF values for faecal excretion (1.9–3.5) are at the lower end of the range (2–5) suggested in the IDEAS Guidelines(4).

To promote the dissemination of knowledge among the internal dosimetry community, a page inside the ENEA Bologna centre web page has been set up (www.bologna.enea.it/attivita/ideas.html/). This site has the aim of promoting the continuation of the activities of IDEAS inside the CONRAD project and will be upgraded as a working tool to meet the needs of the project. For the time being, it is possible to download from this page the three IDEAS databases via the SCK·CEN IDEAS web page (www.sckcen.be/ideas/), the ENEA report on IDEAS WP3, the final report of the IDEAS/IAEA intercomparison exercise and the final version of guidelines as a pdf file (Report FZKA 7243). The following links are also available: the IMIE software web page, ICRP's INDOS public access web page (to download the draft of the ICRP Guidance Document) and the CONRAD WP5 page on the EURADOS web site.

Research Studies on Biokinetic Models

The research activity of this WP5 task is coordinated by BfS (Germany). The impact of the application of new models for occupational dose assessment is to be evaluated, focusing initially on the new HATM(5). Age-dependent doses to members of the public are beyond the scope of this task. Results of this group are important as a support for on-going efforts of the ICRP Committee 2 Task Group on Dose Calculation (DOCAL).

The new ICRP HATM (see Figure 1) has been implemented into six computational codes by six European Institutes (HPA, IRSN, RPI Kiev, BfS and University of Milan and ENEA). As a first step, an intercomparison has been carried out of biokinetic results (i.e. number of disintegrations within HATM compartiments and faecal excretion rates) for a simplified model (direct absorption from the small intestine, without any retention and recycling

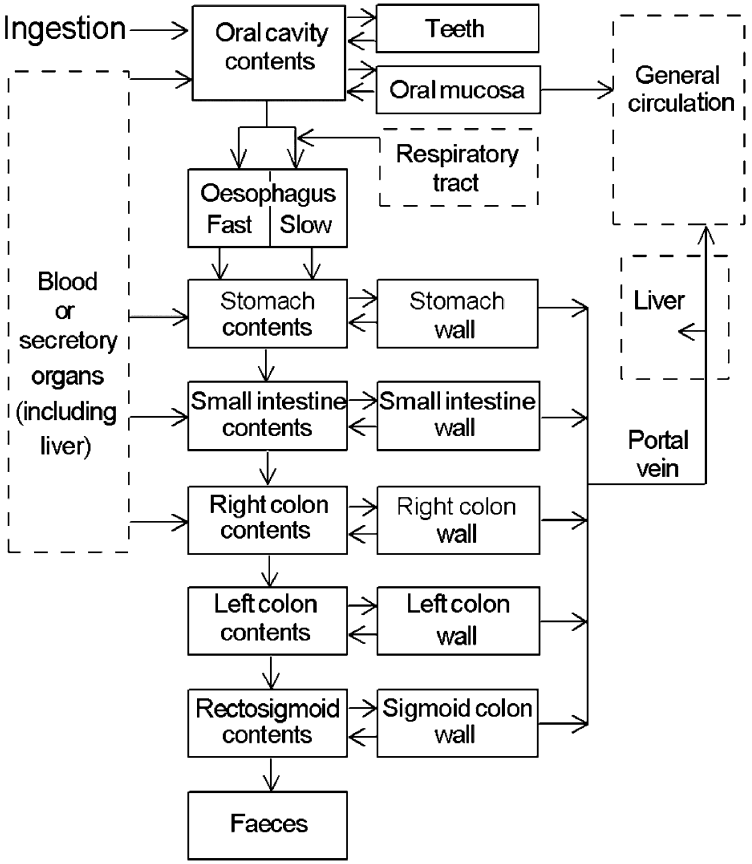

Figure 1. The new ICRP Human Alimentary Tract Model (HATM).

in the wall). Calculations have been made for 11 radionuclides (^{133}Te, ^{18}F, ^{99m}Tc, ^{127}Te, ^{123}I, ^{111}In, ^{201}Tl, ^{141}Ce, ^{60}Co, ^{129}I and ^{238}U) with different half-lives and different f_A absorption values. The results for the number of disintegrations within the compartments of the alimentary tract confirmed a very good agreement and the comparison of faecal excretion rates showed some preliminary discrepancies which were solved; thus all computational results agree in this initial phase of the work.

An important contribution of this working subgroup was the study of the absorption formulation of the new HAT model; the ICRP text has been revised after some inconsistencies were identified by CONRAD partners.

The study has continued with more complicated cases, applying the adult male parameters for total diet without systemic contributions by secretion into the HATM. Three new work topics have been initiated. First, calculations have been made of the number of nuclear transformations of parent and daughter radionuclides within the HATM compartments for two cases: ^{90}Sr/^{90}Y and ^{234}Pu with its progeny ^{234}Np, ^{230}U and ^{226}Th. Second, the absorption from different sites of the alimentary tract for intakes of ^{131}I has been studied, with the assumptions that half of the iodine contained in the stomach is absorbed directly to the blood and that 0.98 of the iodine in the small intestine is absorbed directly to the blood. Third, recycling in the small intestine wall of the alimentary tract has been studied, with calculations performed of the nuclear transformations for ^{59}Fe.

With reference to the ICRP human respiratory tract model (HRTM), no specific work has been planned so far. Some calculation could be carried out in cooperation with the ICRP DOCAL group, to assess the effect of changing default absorption parameters or considering the bound state compartments for specific elements.

At the moment no work with new systemic models is planned, at least until the final version of new ICRP systemic models is published. IRSN has proposed a study for the development of a model describing the effect of administration of DTPA. The NCRP wound model is not available so far, but the CONRAD biokinetic group will be involved in this matter as soon as the structure and default parameters of the model are available.

MC applications for *in vivo* assessment of intakes

New developments in the use of voxel phantoms and MC applications for the assessment of intakes from *in vivo* measurements have been evaluated. Innovative approaches have been generated for the creation and application of voxel phantoms used for MC calculations of calibration factors for whole-body counting systems. The objective of this Task-group coordinated by IRSN (France) is to extend such investigations to the improvement in the reconstruction of numerical anthropomorphic phantoms, taking advantage of recent progress in image-processing codes. Specific applications for *in vivo* monitoring have been studied and a collaboration with CONRAD Work Package 4 (WP4) 'Computational Dosimetry' is established in order to coordinate common areas of work in this field.

This Task is planned to be developed by carrying out an 'Intercomparison on MC modelling for *in vivo* measurements of Americium in a knee phantom'(6). IRSN, CIEMAT and ENEA are involved in the organisation of the exercise (Figure 2). The final goals are the comparison of MC codes and the capability of laboratories to deal with such kind of exercises. A questionnaire titled: 'Expression of interest in taking part in experimental-numerical intercomparison on *in vivo* measurements' was elaborated and sent to potential participants. Up to now, 15 laboratories express its interest answering the questionnaire; 10 of them are able to create numerical phantoms from CT or MR images and for 6 participants, a segmentation tool is available.

CONRAD WP4–WP5 joint collaboration

Intercomparison on Monte Carlo modelling
for *in vivo* measurements of Americium
in a knee phantom

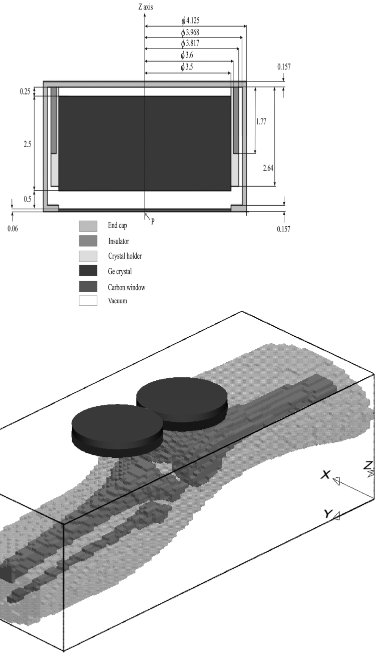

Figure 2. Joint collaboration between Work Package 4 'Computational Dosimetry' and Work Package 5 'Internal Dosimetry' within the Coordinated Action 'CONRAD'.

A CT scan of a plastic anthropometric knee phantom was made by CIEMAT; the production of two sets of raw data was performed (non-segmented and segmented). The files were distributed to the participants to be implemented in their own MC codes. Technical information concerning the LE Ge detectors was provided; the modelling of the counting geometry, with two detectors located over the knee voxel phantom will be required. Final calculations to complete the exercise are needed to obtain the counting efficiency and the full ^{241}Am spectrum.

As a complementary activity to the MC modelling for *in vivo* determination of Americium in a knee voxel phantom, measurements of the Spitz anthropometric knee phantom (fabricated by University of Cincinnati for calibration purposes) have been performed at CIEMAT and IRSN whole-body counting facilities for an *in vivo* intercomparison study. Both laboratories are involved in counting efficiency calculations and in the generation of respective voxel phantoms obtained from CT images of the Spitz phantom obtained in two different hospitals.

A second intercomparison for MC modelling of *in vivo* measurements of Actinides deposited in the lungs of a torso voxel phantom is planned to be prepared at the end of CONRAD Project, coordinated by IRSN.

Interpretation of monitoring data for emergency workers after accidental or deliberate releases of radionuclides (e.g. nuclear terrorism)

The objective of this CONRAD WP5 task coordinated by HPA (UK) and STUK (Finland) is the development of a network of people and organisations with responsibilities for emergency monitoring of emergency services personnel and members of the public, and for assessment of doses resulting from internal and external contamination.

The network has been given the acronym EUREMON (EURopean Emergency MONitoring Network). Its aims are to share information on current strategies and methodologies, and on relevant research and development (R&D) projects. Information collected will be used to define needs for research, advice and training. Individuals who might wish to participate in this network were selected using a number of criteria, including: participation in earlier EU projects relating to monitoring; and/or participation in Work Package 5 of CONRAD; and/or participation in EURADOS work programme, including the EURADOS harmonisation network; and/or a known record of work in this area. The selected individuals were formally invited to join the network, and as of 25 September 2006, 19 positive replies and 3 negative replies had been received, while replies were awaited for 40 invitations. Positive replies had been received from 13 out of 25 EU countries, and from 4 non-EU countries.

A draft questionnaire has been generated that will collect the information required by both Task 5.4 and the TMT Handbook project (see below). Topics covered include available equipment for internal/external contamination monitoring after accidental or deliberate releases, current dose assessment methodologies, currently available dose assessment software and relevant emergency exercises. This questionnaire will be distributed to members of the network as soon as network membership is finalised.

A collaboration has been established with other European projects involved in response to radiation emergencies, including TIARA (Treatment Initiatives After Radiological Accidents) and TMT HANDBOOK, which aims to develop a responder's handbook for the triage, monitoring and treatment of members of the public in the event of the malevolent use of radiation. Some members of the CONRAD Emergency task group are contributing to both projects.

Internal Contamination Databases

The IDEAS Internal Contamination Database is a compilation of published internal contamination cases and represents a very valuable tool for the internal dosimetry community. To ensure that the IDEAS Guidelines are applicable to a wide range of practical situations, a database was compiled of cases of internal contamination, which include monitoring data suitable for assessment. A Bibliographic Database was also set up with references to papers in the open literature dealing with problems related to cases of internal contamination. The 'Evaluation of Cases Database' contains a summary of information about the evaluations. As the CONRAD project proceeds, the first two databases will be updated with new input; SCK-CEN, HPA, AEKI and ENEA are involved in this action. All three IDEAS databases are made available to the internal dosimetry community by setting them for download on a web page named IDEAS Databases hosted at the SCK·CEN web site. This goal fits very well with one of the more important aims of this European Coordinated Action: 'dissemination of knowledge'.

CONCLUSIONS

CONRAD Work Package (WP5) coordinates research in the area of internal dosimetry. One of the achievements of this action is the organisation of the first intercomparison on MC modelling for *in vivo* measurement of ^{241}Am in a knee voxel phantom; this exercise has been prepared in connection with CONRAD WP4. Further achievements are connected with the application of the new ICRP HATM with subsequent QA calculations using different codes. A page inside the ENEA Bologna centre web site has been set up, to permit to continue the activities of IDEAS group within the CONRAD Project. SF values have been evaluated for different radionuclides and types of monitoring data using real data contained in the IDEAS Internal Contamination Database. In addition, software is currently being developed to estimate uncertainty on the assessed dose from monitoring data. A questionnaire was generated to collect information from persons in charge of the individual monitoring programmes that would be brought into operation after accidental or deliberate releases of radionuclides; a European Emergency Network for Individual Monitoring (EUREMON) is in the process of being established. IDEAS databases are available at the SCK·CEN and ENEA web pages; now the CONRAD group is looking for new cases.

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EVALUATION OF SCATTERING FACTOR VALUES FOR INTERNAL DOSE ASSESSMENT FOLLOWING THE IDEAS GUIDELINES: PRELIMINARY RESULTS

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The IDEAS Guidelines for the assessment of internal doses from monitoring data suggest default measurement uncertainties (i.e. scattering factors, SFs) to be used for different types of monitoring data. However, these default values were mainly based upon expert judgement. In this paper, SF values have been calculated for different radionuclides and types of monitoring data using real data contained in the IDEAS Internal Contamination Database. Results are presented.

INTRODUCTION

The recently developed guidelines(1) for the assessment of internal doses from monitoring data (IDEAS Guidelines) suggest default measurement uncertainties (i.e. scattering factors, SFs) to be used for different types of monitoring data. Realistic SF values are important because:

- They are needed to assess the uncertainty in the estimated intake and dose.
- They determine the relative weighting of data in fitting process and can affect the estimated intake when different types of monitoring data are used simultaneously.
- They enable rogue data to be identified objectively.
- They enable objective (statistical) criteria (goodness-of-fit) to be calculated, which are used to determine whether the predictions of the biokinetic model (with a given set of parameter values) used to assess the intake and dose are inconsistent with the measurement data.

The Guidelines consider the measurement uncertainty as consisting of two categories: Type A and Type B. Type A uncertainties are due to counting statistics and Type B uncertainties are due to all other sources of uncertainty such as those relating to calibration(1).

The IDEAS Guidelines assume the overall uncertainty on an individual monitoring value can be described in terms of a log-normal distribution and the SF is defined as the geometric standard deviation (GSD). This approximation is valid if Type A errors are relatively small ($<30\%$). Thus, it is assumed that if the measurements could be repeated, hypothetically at the same time, then the distribution of the measurement results could be described by a log-normal distribution.

The default SF values proposed in the IDEAS Guidelines are based mainly upon expert judgement. The aim of the present work is to evaluate, mathematically, SF values for different radionuclides and types of monitoring data using real data contained in the IDEAS Internal Contamination Database(2). Results of SF values for some radionuclides and types of monitoring data are presented.

PROCEEDURE

For each case considered, it is assumed that the measurements come from the same distribution (i.e. the SF is the same for each measurement).

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Data affected by decorporation therapy were excluded. Only those cases with more than 15 data points after the end of exposure were selected. Cases with low levels of activity were avoided so that the main component of the SF would be due to Type B errors. Cases with many <LLD values (i.e. measurements reported as being below the lower limit of detection) were excluded or if a case had <LLD values then the data following the <LLD values were discarded. For each case, the following three steps were carried out.

Step 1: Determine the trend of data

The trend of the data was determined by fitting a sum of exponential terms to the data assuming errors are log-normally distributed (Figure 1).

The lowest number of exponentials that gives a good fit to the data was used. This was determined by the use of the autocorrelation coefficient test statistic (ρ-test statistic)(3). In practice the exact procedure was not always followed because on a few occasions, the fit was accepted as it was judged that the fit displayed graphically looked reasonable to the eye even though the ρ-test failed.

The ρ-test statistic essentially rejects the fit if all, or a long series of, data are systematically underestimated or overestimated. The advantage of this test statistic is that it is not sensitive to the assumed measurement uncertainty.

Step 2: Determine the SF

The SF value was determined by calculating the GSD of the data (M_i) around the trend (i.e. predicted quantities, p_i).

$$\sigma^2 = \frac{\sum_{i=1}^{n}[\ln(M_i) - \ln(p_i)]^2}{n - z} \quad \text{and} \quad SF = e^{\sigma} \tag{1}$$

where z is the number of parameters used to determine the trend of the data (two for each exponential term).

Step 3: Test to see if the data are log-normally distributed

If the measurements are log-normally distributed around the trend of the data then the M_i/p_i values are log-normally distributed with a median of 1.0. The chi-squared (χ^2) test was used to test whether the distribution of the M_i/p_i values is consistent with a log-normal distribution by comparing the occurrences in the observed frequency distribution with the expected occurrences based on the theoretical log-normal distribution. However, the limitation of the χ^2-test is that it is only valid for large n. So future work will consider other test statistics such as the Anderson–Darling test statistic or the Shapiro–Wilk test statistic.

Combining data from different cases

Data of the same monitoring type, the same route of intake and the same element from different cases (i.e. subjects) were combined to obtain an overall SF by applying equation (1). For example, if there are two subjects (a and b) then equation (1) can be extended as follows:

$$\sigma^2 = \frac{\sum_{i=1}^{n^a}[\ln(M_i^a) - \ln(p_i^a)]^2 + \sum_{i=1}^{n^b}[\ln(M_i^b) - \ln(p_i^b)]^2}{n^a - z^a + n^b - z^b}$$

where the parameters with a superscript a refer to subject a and those parameters with a superscript b refer to subject b. Again the SF value is equal to $\exp(\sigma)$. Combining data from different cases is valid if the values of M_i/p_i come from the same log-normal distribution.

RESULTS

In most of the cases it was possible to determine the trend of the data with a single exponential term or with the sum of two exponential terms. A few of the cases required a sum of three exponential terms.

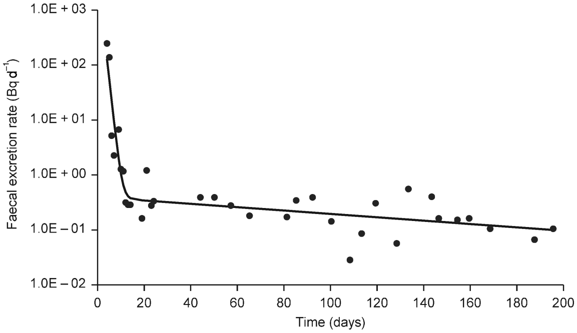

Figure 1. A sum of two exponential terms fitted to the faecal data of Case 157(2) (inhalation of ^{239}Pu).

Table 1. Scattering factor (SF) values for different nuclides and types of monitoring data. The 95% confidence intervals are in parentheses.

Nuclide	Type of monitoring	Route of intake[a]	No. of cases	No. of data	SF	Range of SF values[b]
Pu	Faeces	W	2	111	3.1	2.9–3.5
Pu/Am	Faeces	Inh	8	217	2.5	1.9–3.5
Pu/Am	Urine	W	5	188	1.7	1.3–2.4
Pu	Urine	Inh	10	371	1.7	1.4–2.0
^{241}Am	Urine	Inh	5	105	1.6	1.2–2.2
Uranium	Urine	Inh	4[(c)]	190	1.8	1.4–2.0
Uranium	Urine	W (burns)	1	46	1.6	
^{90}Sr	Urine	Inh	4	173	1.6	1.3–1.8
^{60}Co	Urine	Inh	2	20	1.8	1.77–1.82
^{32}P	Urine	Ing or Inj	2	75	1.21	1.15–1.28
^{3}H (HTO)	Urine	Inh	3	233	1.08	1.01–1.10
^{137}Cs	WB count	Inh or Ing	5	103	1.16	1.02–1.27

[a] inh = inhalation, ing = ingestion, inj = injection and W = wound.

[b] Ranges of the SF values calculated for the individual cases.

[c] Other uranium cases were evaluated, e.g. there were three cases where urine samples were averaged and these cases gave SF values of ~1.7. Another example included four cases where additional intakes could not be ruled out and these gave SF values of ~2.3.

Results for the SF values are presented in Table 1. The measurements for the individual cases that had sufficient data (i.e. $\sim n > 35$) were found to be consistent with the assumption that the data are log-normally distributed (i.e. the χ^2-test did not fail) apart from one case (Case 42, Pu in urine, wound). When combining the cases, the combined data sets were also consistent with the assumption that the data are log-normally distributed apart from urinary data for plutonium, americium and tritium, and whole-body measurements of ^{137}Cs. For these cases it cannot, strictly, be assumed that the values of M_i/p_i come from the same log-normal distribution. Nevertheless, the SF values for the combined cases are given as an indication of the uncertainty in the data.

DISCUSSION OF RESULTS

Faecal data

The SF values for faecal excretion range from 1.9 to 3.5 for the individual cases (Table 1). These values are at the lower end of the range (2–5) suggested in the IDEAS Guidelines. Bull(4) determined SF values between 2 and 3 for systemic faecal excretion from volunteer data, which is in agreement with the values calculated in this paper.

The SF values for wound are higher than that from inhalation. Differences may arise because of the different biological processes involved in the uptake and because wound represents systemic faecal excretion whereas for inhalation of relatively insoluble materials a large component is from particle transport from the lung. However, only two cases were assessed for wound so no firm conclusions can be drawn. Combining the wound cases with the inhalation cases gives a SF of 2.7. The combined data are consistent with the assumption that the data are log-normally distributed (i.e. the χ^2-test did not fail).

Urine data

In general, for Type B errors, the main component of the SF values results from the uncertainty in the collection period, which depends on the sampling procedures and the technique used to normalise the data to 24 h. Moss *et al.*(5) showed that when the sampling method and analytical procedures are carefully controlled for true 24-h urine samples of plutonium, over 5 d, then the SF is ~1.1 whereas for routine monitoring data the authors obtained a higher value of 1.9. This is in agreement with the SF value calculated from data obtained from a volunteer experiment where the sampling procedures were carefully controlled (Case 127(2), inhalation of fission products). For this case, the SF values for urinary excretion of ^{60}Co and ^{137}Cs were <1.1. This shows that the scatter caused by biological variation is low.

The SF values for urinary excretion of plutonium, americium, uranium, strontium and cobalt are similar, ~1.7 (Table 1). Also there is little variation between routes of intake. This is expected, as the biological variation is likely to be less than the uncertainty in the collection period. The values ranged from 1.2 to 2.4 for the individual cases.

In general, information on sampling procedures and the method used to normalise the data to 24-h excretion is not given on the IDEAS database. For one of the Cases (Case 204, Am/Pu, wound), the data were normalised by the amount of creatinine excreted per day. The SF value was ~1.3. At Los Alamos National Laboratory (USA), Type B uncertainties for plutonium in urine measurements normalised using volume or specific gravity were also found to have a SF value of 1.3(6). Plutonium in urine measurements of Sellafield nuclear plant (UK) workers normalised by creatinine indicates a SF value of 1.8(7). However, because sampling procedures and measurement techniques have improved over the years at Sellafield, recent measurements are likely to have a SF value <1.8.

For intakes of tritiated water (HTO) the activity concentration in urine is required and not the 24-h excretion rate. As a result the SF is lower (1.1).

In vivo data

The SF for whole-body measurements of ^{137}Cs, which emits a photon energy >100 keV, is on average 1.16 and this agrees with the IDEAS suggested value of 1.15.

CONCLUSION

In this paper, an empirical approach based on statistical analysis of real monitoring data taken from the IDEAS Internal Contamination Database has been used to evaluate SF values. Results have been presented in Table 1 for different types of monitoring data. In the future, further analysis should be carried out, particularly for those elements and routes of intake for which the log-normal test on the pool of data from different subjects fails. Results are broadly in agreement with the values suggested in the IDEAS Guidelines, which were based mainly on expert judgement. However, the SF values for faecal excretion (1.9–3.5) are at the lower end of the range (2–5) suggested in the IDEAS Guidelines.

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INTERNAL DOSE ASSESSMENTS: UNCERTAINTY STUDIES AND UPDATE OF IDEAS GUIDELINES AND DATABASES WITHIN CONRAD PROJECT

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Abstract

The work of Task Group 5.1 (Uncertainty studies and revision of IDEAS Guidelines) and Task Group 5.5 (update of IDEAS databases) of the CONRAD project is described. Scattering factor (SF) values (i.e. measurement uncertainties) have been calculated for different radionuclides and types of monitoring data using real data contained in the IDEAS Internal Contamination Database. Based upon this work and other published values, default SF values are suggested. Uncertainty studies have been carried out using both a Bayesian approach as well as a frequentist (classical) approach. The IDEAS Guidelines have been revised in areas relating to the evaluation of an effective AMAD, guidance is given on evaluating wound cases with the NCRP wound model and suggestions made on the number and type of measurements required for dose assessment.

INTRODUCTION

The (CONRAD)(1) project, "A Coordinated Network for Radiation Dosimetry", started in April 2005 and ended in February 2008, and was funded within the EURATOM 6th Framework Programme for research and training in nuclear energy (contract No FI6R-012684).

Work Package 5 of the CONRAD project, headed by M. A. Lopez, was dedicated to the coordination of research on internal dosimetry(1). This workpackage was subdivided into five Task Groups. Task Group 5.1 covered uncertainty studies and the revision of the IDEAS Guidelines(2). Seventeen scientists from nine European countries worked within this Task Group, jointly coordinated by J. W. Marsh and C. M. Castellani. Task Group 5.5 dealt with the update of the IDEAS internal contination database(3) and this task group was headed by C. Hurtgen.

UNCERTAINTY STUDIES

Evaluation of measurement uncertainties for internal dose assessment

The recently developed guidelines(2) for the assessment of internal doses from monitoring data (IDEAS Guidelines) suggest default measurement uncertainties (i.e. scattering factors, SF) to be used for different types of monitoring data.

The Guidelines consider the measurement uncertainty as consisting of two categories: Type A and Type B. Type A uncertainties are due to counting statistics and Type B uncertainties are due to all other sources of uncertainty such as those relating to calibration.

The IDEAS Guidelines assume that the overall uncertainty on an individual monitoring value can be described in terms of a lognormal distribution and the SF is defined as its geometric standard deviation (GSD). This approximation is applicable to cases where the counts are relatively large (i.e. when $SF_A < 1.4$). Miller (2007)(4) considers this lognormal approximation to be reasonable if the ratio $\ln(SF_A) : \ln(SF_B)$ is less than 1/3. In cases where the counts are low (i.e. SF_A is high) then Miller et al. (2002)(5) consider that the exact likelihood function they describe should be used. The exact likelihood function is the probability distribution of measurements given an intake.

As part of this project, work was carried out to calculate SF values for different radionuclides and types of monitoring data using real data contained in the IDEAS Internal Contamination Database(3). The results of this work have already been published by Marsh et al. (2007)(6).

The SF values for different types of measurements given in Table 1 were suggested by the CONRAD Group as default values where information specific to the case is not available. These values are based upon the work carried out here(6), the values suggested by the IDEAS project(2) and upon the studies of Moss et al. (1969)(7), Riddell and Britcher (1994)(8) and Miller (2004)(9).

The SF values suggested in the IDEAS Guidelines for in-vivo measurements are applicable to chest and total body in-vivo measurements and are consistent with the values determine here(6). It is noted that specialised in-vivo measurements such as knee and head measurements to determine skeleton activity have much larger uncertainties compared with chest and total body activity measurements. For example, Vrba (2007)(10) estimated uncertainties of about 20% due to variation in activity distribution for head measurements of ^{241}Am whereas for chest measurements the corresponding uncertainty is only about 5%(2).

Classical Statistics

Within the group there was great deal of debate on how to interpret probability and how to apply classical statistics to retrospective internal dosimetry. This was then compared with the Bayesian approach.

In the frequentist method, probability is interpreted as a limiting frequency of the outcome of a repeatable experiment. The uncertainty of a given parameter value is expressed in terms of a confidence interval with a specified level of confidence, for example the 95% confidence interval. It is important to realise that the parameter value is unknown but has a fixed true value whereas the ends of the confidence interval are variables. This means that, for example, the 95% confidence interval is interpreted as follows: If the experiment is repeated many times, calculating a confidence interval each time, then 95% of the intervals would include the true fixed parameter value. In the frequentist method one cannot, therefore, define a probability for a hypothesis or a probability density function (pdf) for a parameter. However, the pdf for a parameter *estimate* can be inferred from the frequency distribution of the outcome. For example, the pdf for the intake *estimate* can be inferred from the frequency distribution of the measurements for a given true intake. This approach was used to investigate the effects of different intake assumptions for the assessment of routine monitoring data.

Intake pattern assumptions for the assessment of routine monitoring data

To estimate intakes from routine monitoring data ICRP recommends an assumption that the intake occurs at the mid-point of the monitoring period. Puncher et al. (2006)(11) and Birchall et al. (2007)(12) showed that this mid-point method leads to biased estimates of intake. That is if this method is applied over a long period of time it will tend to, on average, overestimate the worker’s real intake. In order to avoid this biasing the authors suggested that a constant chronic intake throughout the monitoring interval should be assumed. This was shown to lead to unbiased estimates of intake, i.e. if this constant chronic method is applied over a long period of time, on average it will tend to estimate the worker’s total true intake. Work carried out within this project has also shown this to be true when the measurement uncertainty is assumed to have a normal distribution, (i.e. the measurement itself is unbiased). It was also shown by example of a tritiated water contamination case, that more than 50% of the workers will have their intake underestimated compared with the true value if the constant chronic method is applied. For the mid-point method, more than 50% of the workers will have their intake overestimated.

Bayesian Statistics

In the Bayesian approach, the interpretation of probability is more general and includes a *degree of belief.* One can then speak of a probability density function for a parameter, which expresses one’s state of knowledge about where its true value lies. Using Bayes’ theorem the prior degree of belief (i.e. what is known about a parameter value before the measurements are observed) is updated by the data to give a posterior pdf for the parameter given the measurement data. The interpretation of the 90% credible interval obtained from the posterior pdf is that, there is a 90% probability that the true value is within the interval.

For a single measurement the posterior pdf depends on the prior distributions. However, as the number of measurements increase, the posterior pdf becomes less dependent upon the prior distributions, and it is therefore more justifiable to infer conclusions from the posterior distribution.

Within the group, the Bayesian approach was implemented(13) and applied to a tritiated water contamination case for comparison purposes. Good agreement was obtained for the posterior distributions of the intake and the time of intake.

REVISION OF IDEAS GUIDELINES

A new webpage, http://www.bologna.enea.it/attivita/ideas.html, has been developed as an internal dosimetry site, providing details of the status of the IDEAS Guidelines and the work related to tasks 5.1 and 5.5 of the CONRAD project.

Number and Type of data required for assessment.

The IDEAS Guidelines suggested the minimum number and type of monitoring data required for dose assessment for some selected radionuclides based upon experience and expert judgement. Its main purpose was to illustrate the point that more measurements should be taken the greater the dose estimate. This work has been extended for different categories of radionuclides (Table 2). It should not be seen as being at all prescriptive and is intended to stimulate discussion and further work on this topic.

Effective AMAD evaluation

The Guidelines suggests evaluating the effective AMAD by calculating the ratio of cumulative faecal excretion over the first 3 days to lung retention on day 3 for relatively insoluble materials(2). This ratio is approximately equal to the initial amount deposited in the upper respiratory tract divided by the amount in the lower respiratory tract. This work has been extended to deal with ^{60}Co cases when there are no direct lung data but whole body data instead. In this case, the whole body measurement on day 10 is used to infer the initial amount deposited in the lower respiratory tract(14). The ratio as a function of effective AMAD has also been expressed as a polynomial function and displayed graphically for Type M and S materials of ^{60}Co and ^{241}Am – see website.

Application of NCRP wound model

Recently, the NCRP has developed a biokinetic model for radionuclide contaminated wounds(15). In this model wound retention is described by five compartments and the material is removed from the wound site by transport into blood directly or via the regional lymph nodes. The NCRP model defines seven default wound retention categories relating to the chemical and physical properties of the material. There are four categories for soluble material (weak, moderate, strong and avid) and categories for particles, fragments and colloids. The particle category contains material, typically relatively insoluble, whose individual sizes are ≤ 20 μm whereas the fragment category includes larger particles and fragments whose size and/or quantity of material are sufficient to cause a foreign body tissue reaction. The colloid category consists of radionuclides that exist as frank colloidal material prior to deposition, and typically have small fractions of the deposited amount that clear rapidly from the wound site (< 20%).

No guidelines exist on how to assess wound cases. Before such guidelines can be developed, it is necessary to gain some experience in assessing wound cases. So it was agreed to use the NCRP wound model to evaluate some plutonium wound cases contained in the IDEAS Internal Contamination Database(3). Cases where decorporation therapy was used were not considered. The following six wound cases were selected: case numbers 42, 234, 235, 236, 237 and 238. Case 42 is described by Bramson et al. (1972)(16), and the other cases are described by Falk (2006)(17). For each case, the urine data were used to evaluate the intake.

As suggested in the IDEAS Guidelines(18) the χ^2 test was used as a measure of the goodness of fit and the fit is rejected at the 5% level of significance. A SF value of 1.7 was assumed for the urine data(6).

The daily urinary excretion function per unit activity deposited in wound for plutonium have been provided by Ishigure(19) for each of the default retention categories. Ishigure derived these functions by implementing the NCRP wound model and the ICRP Publication 67 systemic biokinetic model for plutonium(20). These functions were used in the assessment of these cases.

Table 4 gives a summary of the results for all the evaluations. In cases 42, 235 and 237, rogue data were identified using the procedure described in the IDEAS Guidelines, and these outliers were excluded from the dataset. Good fits to the urine data have been obtained for four cases (case numbers 42, 234, 235 and 236). Figure 1 shows the model fit to the urine data of case 42 assuming the soluble strong default category.

For case 235, the soluble strong category gave a poor fit to the early urinary excretion data but a good fit to the data after 10 days. To improve the fit the overall output transfer rate from the “soluble” compartment of the NCRP wound model was reduced by a factor of 10. The resulting fit was not rejected by the χ^2 test. In this case, the estimated activity deposited in the wound obtained from the urine data was about a factor of 4 greater than the direct measured value (Table 4). However, the uncertainty associated with direct wound measurements needs to be considered when making such comparisons. This is particularly, true for alpha emitters like ^{239}Pu where it is difficult to determine calibration factor because of alpha attenuation in overlying tissue.

It was not possible to obtain a good fit with default wound retention categories for cases 237 and 238. This is because of the large scatter of the data and because the daily urinary excretion remains practically constant during a protracted time range (up to more than 10000 days). Further investigation is required.

Discussion inside the group covered problems on how to deal with cases where it is not possible to obtain a good fit to the data with one of the default retention categories. One suggestion was to assume a mixture of two default retention categories, either inside the “soluble category” (weak, moderate, strong and avid) or inside the “insoluble category” (colloid, particles or fragment). Another option would be to vary model parameter values. However, which parameters should be varied and to what extend are questions that still need to be answered.

IDEAS DATA BASES

During the IDEAS project(2), three databases: the Bibliographic Database, the Internal Contamination Database and the Evaluation Database have been developed(3, 21).

The Bibliographic Database is a compilation of publications from the literature, which contain information on cases of internal contamination from which intake and committed doses could be assessed. During the CONRAD project, new references have been added to the database, some references have been corrected and repeated references have been removed.

The Internal Contamination Database(3) contains cases of internal contamination compiled from references of the previous database. For each case, the case description and the monitoring results are given. During the CONRAD project, new cases have been added to the database, so it now contains 255 cases.

Also available is the Evaluation Database. In Work Package 3 of the IDEAS project(21), evaluations provided by the contractors were collated in an Evaluation of Cases Database.

All these databases are available for download at http://www.sckcen.be/ideas/. Please contact C. Hurtgen (churtgen@sckcen.be) if you have a contamination case with intake of radionuclides as we would like to add it to the database.

CONCLUSIONS

It was very important to draw on the group members’ expertise especially in the revision of the guidelines. The CONRAD group has suggested (i) default SF values for various types of measurements, and (ii) minimum numbers and types of monitoring data required for reliable dose assessment for different categories of radionuclides. However, these suggestions are open for discussion. More work is still required on developing guidelines, especially with regard to the assessment of wound cases.

Discussions among members of the group were useful in understanding the concepts of classical statistics and Bayesian statistics applied to retrospective dosimetry. In the future, it is planned to use the Bayesian approach to estimate the conditional probability of the intake or dose given the measurement data for special monitoring programmes. Such studies can be used to determine the minimum number of measurements required to estimate an intake and dose with a given uncertainty.

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Table 1 Suggested default values for the scattering factor (SF) for various types of measurement (Type B errors). Ranges are given in parentheses

Quantity	Type B scattering factor, SF_B
True 24-hr urine	1.1(a)
Activity concentration of ^{3}H in urine	1.1(b)
Simulated 24-hr urine, creatinine or specific gravity normalised.	1.6(b) (1.3(c) - 1.8(d))
Spot urine sample	2.0(a)
Faecal 24-hr sample	3 (2 - 4)(b)
Faecal 72-hr sample	1.9 (1.5 – 2.2)(e)

(a) Value given by Moss et al, 1969(7) based on plutonium in urine measurements of workers at Los Alamos. The SF value for true 24-hr urine samples is based on samples collected and processed under special, closely controlled, conditions.

(b) Value based on judgement and on values calculated here, Marsh et al. (2007)(6).

(c) At Los Alamos, Type B uncertainties, in terms of the coefficient of variation, for urine samples normalised using volume and specific gravity has been found to be 30% (i.e. a SF of 1.3)(9).

(d) Value given by Riddell et al, 1994(8) based on plutonium in urine measurements of Sellafield workers. Because sampling procedures and measurements techniques have improve over the years recent measurements are likely to have a SF less than 1.8.

(e) The SF values for 72-hr faecal samples were calculated from the SF values for 24-hr faecal samples

Table 2 Suggested minimum number and type of data required for assessment of dose for some categories of radionuclides.

Category of radionuclide	Type of monitoring	Number of required monitoring data		
		D < 1 mSv (minimum requirement)	1 mSv < D < 6 mSv[a]	D > 6 mSv[b]
All type of α-emitters with significant γ-component (U-235, Am-241 etc.)	Urine	-	2	3
	Faeces	1	2	3
	Whole body, critical organ or wound site, respectively.	-	2	4
All type of α-emitters without significant γ-component (Po-210, Pu-239 etc.)	Urine	-	3	5
	Faeces	1	3	5
All type of β-emitters with significant γ-component (Co-60, I-131, Cs-137 etc.)	Whole body, critical organ or wound site, respectively.	1	2	4
	Urine	-	2	4
F-type β-emitters without significant γ-component (H-3, C-14 etc.)	Urine	1	4	8
M/S-type β-emitters without significant γ-component (Sr-90 etc.)	Urine	1	2	4
	Faeces	-	2	4
Pure γ-emitters (I-123 etc.)	Whole body or critical organ	1	2	4
	Urine	-	2	4

a) The monitoring data should cover a time range of 30 d; if the effective half-life is less than 30 d, the monitoring data should cover a time range corresponding to the effective half-life.

b) The monitoring data should cover a time range of 60 d; if the effective half-life is less than 30 d, the monitoring data should cover a time range corresponding to twice the effective half-life.

Table 3 Summary of the results for the assessment of wound cases

Case number	No. of outliers	Urinary excretion behaviour	Wound retention category	Fit(a)	Deposited activity(b) (Bq)	
					Estimated(c)	Measured
42	1	Decreasing	Soluble strong	Accepted	465	-
234	0	Nearly constant	Colloid	Accepted	1907	1570 ± 300
235	1	Decreasing	Modified soluble Strong (d)	Accepted	1641	410
236	0	Nearly constant	Colloid	Accepted	1684	480
237	4	Nearly constant	Colloid	Rejected(e)	-	
238	0	Nearly constant	Colloid	Rejected(e)	-	

(a) The χ^2 test was used as a measure of goodness of fit and the fit was rejected at the 5% level of significance. A SF of 1.7 was assumed for the urine data(6).
(b) Activity of plutonium (^{238,239,240}Pu) deposited in the wound.
(c) Estimated from the urine data.
(d) The overall output transfer rate from the "soluble" compartment of the NCRP wound model was reduced by a factor of 10.
(e) Not possible to obtain a good fit with any of the default wound retention categories assuming a SF of 1.7(6).

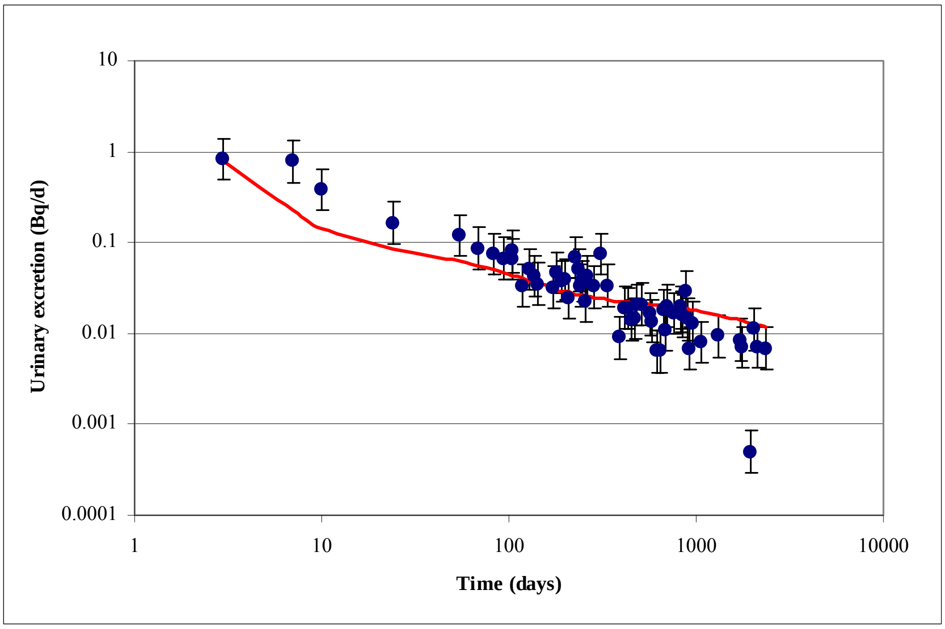

Figure 1. Model fit (—) to urine data (•) of case 42 assuming the default wound soluble strong retention category. The data point below 0.001 Bq/d was identified as an outlier.

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DEVELOPMENT, IMPLEMENTATION AND QUALITY ASSURANCE OF BIOKINETIC MODELS WITHIN CONRAD

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Abstract: The work of the Task Group 5.2 "Research Studies on Biokinetic Models" of the CONRAD project is presented. New biokinetic models have been implemented by several European institutions. Quality assurance procedures included intercomparison of the results as well as quality assurance of model formulation. Additionally the use of the models was examined leading to proposals of tuning parameters. Stable isotope studies were evaluated with respect to their implications to the new models and new biokinetic models were proposed on the basis of their results. Furthermore, the development of a biokinetic model describing the effects of decorporation of actinides by DTPA treatment was initiated.

INTRODUCTION

In this paper the work of Task Group 5.2 of the concerted action "A Coordinated Network for Radiation Dosimetry" (CONRAD)(1) is presented which started at the beginning of 2005 and was running until end of March 2008. This project was funded within the EURATOM 6th Framework Programme for research and training in nuclear energy (contract No FI6R-012684). It involved two main activities to maintain and enhance competence in radiation protection dosimetry: It analysed the options for sustainable networks linking research players and end users and it coordinated research concerning measurements and calculations for radiation protection at workplaces.

CONRAD was structured into 7 work packages. The objective of work package 5 "Internal Dosimetry" which was headed by M. A. Lopez was the coordination of research on assessment and evaluation of internal exposures(2). This work package was subdivided into 5 Task Groups including Task Group 5.2 "Research Studies on Biokinetic Models". Sixteen scientists out of six European countries were working within this Task Group, headed by D. Noßke, in order to coordinate research studies on biokinetic models and to evaluate the implications of new biokinetic models on dose assessment and safety standards for workers.

To this aim several new biokinetic models (the ICRP Human Alimentary Tract Model (HATM)(3), the NCRP wound model(4) and several new systemic models) were implemented and the computational results were quality assured by intercomparison procedures. This kind of work also included the evaluation of stable isotope studies and the development of a biokinetic model for the mechanisms of decorporation of actinides by diethylenetriaminepentaacetic acid (DTPA).

IMPLEMENTATION AND QUALITY ASSURANCE OF BIOKINETIC MODELS

ICRP is preparing a revision of its Publications 30(5), 54(6), 68(7), and 78(8) related with internal doses to occupationally exposed workers and their individual monitoring. This revision will include (1) the new HATM(3), (2) individual absorption parameters within the ICRP Human Respiratory Tract Model (HRTM)(9) different from the default Types F, M, and S, (3) new systemic biokinetic models, (4) examples for the use of the new NCRP wound model(4) as well as (5) new dosimetric parameters based on voxel models(10) of the ICRP male and female adult reference persons and (6) the new concept of ICRP to calculate the effective

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dose(11). The aim of the Task Group's work is to evaluate the impact of the applications of new models for dose assessment, e.g. the new HATM, the NCRP wound model and new revised systemic models.

Implementation of the HATM

The new HATM(3) was implemented into computational codes by six different groups in five European countries. Compared to the old gastrointestinal model of ICRP Publication 30(5) the most significant changes in biokinetics are the addition of the initial compartments of oral cavity and oesophagus with mean retention times of only several seconds and the possibility of absorption not only directly from the small intestine but from nearly all sites of the tract with potential retention in the walls and subsequent recycling into the contents of the tract.

Quality assurance of the model implementation

Quality assurance procedures were started by comparing results of numbers of disintegrations within the compartments of the alimentary tract as well as daily faecal excretion rates for several radionuclides with different half-lives ranging from a few minutes (^{133}Te) to billions of years (^{238}U) and different values of fractions of ingested activity which are absorbed to blood, f_A, ranging from 0.0005 to 0.99. For these calculations it was assumed that - as in the old model(5) - absorption to blood is only directly from the small intestine without retention in the wall. For these calculations the transfer rates for diet and the adult male were used. The results show that for these radionuclides with half-lives of more than 12 minutes the numbers of disintegrations in the oral cavity and the oesophagus are independent of the half-life. The numbers of disintegrations in the stomach tend to be a little bit larger than those predicted by the old gastrointestinal model due to the slightly longer mean retention time of 70 minutes in the HATM compared to 60 minutes in the old gastrointestinal model while - with the exception of the short-lived radioisotopes - the results are identical for the small intestine. Similarly the sum of the numbers of disintegrations in the colon compartments (right, left and rectosigmoid colon for the HATM, upper and lower large intestine for the old gastrointestinal model) is nearly the same for both models.

At a next step, those calculations were performed not only for parent nuclides but also for members of the decay chains of ^{90}Sr, ^{230}U, and ^{234}Pu (these radioisotopes have been chosen because of the structure of their decay chain, not because of their importance in radiation protection). In these cases the numbers of transformations of the daughter nuclides in the first fast-clearing compartments are up to 4 orders of magnitude lower than those for the parent nuclide while these values become closer to the parents' values in the colon compartments.

Other computational examples referred to some new features of the HATM compared to the old gastrointestinal model: Two examples from ICRP Publication 100(3) were chosen. One example dealt with ^{131}I which is absorbed not only from the small intestine but additionally (50%) from the stomach, the other example (based on Werner *et al.*(12)) dealt with ^{59}Fe which is retained within the small intestine wall during the absorption process and partly recycled into the small intestine content. For this it was assumed that 50% of the small intestine content is taken up by the small intestine wall and retained there with a biological half-time of 14.2 h and then removed to blood (25%) or back to the small intestine content again (75%).

The comparison of the computational results showed excellent agreement: The discrepancies in the results of numbers of disintegrations calculated by different codes were less than 1%. The discrepancies in the results of the daily excretion rates were a little bit larger than those of the numbers of disintegrations but at the end also did not exceed 1%.

It could also be seen that the application of analytical and numerical, e.g. Runge-Kutta, methods both used by the BfS code DOSAGE showed almost no discrepancies amongst themselves. Only for the very short-lived radionuclide ^{133}Te these were up to 0.2% in the last compartments of the tract. This demonstrates that in spite of the very short transit times of a few seconds in the mouth and oesophagus analytical methods can also be applied for the computations.

Quality assurance of model formulation

It was recognised that the model implementation work is also a very efficient means of quality assurance for the model description. During the implementation of the HATM, some inconsistencies concerning total and regional absorption fractions were discovered in the draft ICRP text(13). This inconsistency could be corrected before the final publication of ICRP Publication 100.

Unfortunately, another inconsistency could not be corrected in time: For the model for iron absorption mentioned above, a simplified model is given in ICRP Publication 100 which is told to be equivalent to the recycling model. This simplified model avoids recycling in the small intestine wall, and iron taken up to the small intestine wall is removed to blood and the right colon content. The calculations showed that the numbers of transformations in the colon compartments are approximately the same in both models but the numbers of transformations in the small intestine contents and wall are underestimated by the simplified model by about 60% while the faecal excretion rates differ up to 37% with the excretion rate being higher in the first 2 days and lower the next days for the simplified model. On the other hand the work of our group demonstrated that the original model could easily be implemented so that there is no need for a simplified model.

NCRP Wound Model

A new biokinetic model for wound contamination has been published by NCRP$^{(4)}$. In this model, the wound is described by five compartments and the material is removed from the wound site by transport into blood directly or via the regional lymph nodes.

This NCRP model defines seven default wound retention categories which are to be used according to the material involved: There are four categories for soluble material (weak, moderate, strong and avid) and categories for colloids, particles and fragments (which are large particles of more than 20 µm diameter). There are different uptake compartments for soluble material, colloids, particles and fragments and for each of these default categories only some of the five wound compartments are used.

The model was implemented by six groups and the wound retention was calculated for the relatively short-lived ^{131}I and the very long-lived ^{239}Pu. The results of the calculations agreed perfectly for ^{239}Pu while for ^{131}I there were significant differences at long times after wound contamination due to the use of different half-lives: Besides the value of 8.04 d used at present by ICRP$^{(14)}$ values of 8.02 d and 8 d were used.

The results show a very wide range of wound retention characteristics of the seven default categories: While for the weakly soluble material only 0.0017% is retained in the wound after 100 d, for the fragments after 10,000 d still 96.6 % would be retained without medical intervention.

Our calculations used the parameters given in a very late draft of the NCRP wound report. The results showed unexpectedly that after about one year the wound retention of the avidly retained soluble material would be less than that of the strongly retained soluble material. Fortunately NCRP could change the parameters of the avidly retained soluble material before the publication of the report to avoid this unexpected result.

Besides the transfer rates for the wound model, sums of up to three exponential functions are given in the NCRP wound report which should approximate the wound retention function for the seven categories. The results obtained with the model parameters were compared with those calculated with these exponential functions. It was demonstrated that the results from these two methods were quite different in some cases: For the colloids, for example, the wound retention calculated with the exponential functions were less by about 15% in the first year compared to those calculated with the transfer rates.

However, because for all default categories only a few compartments of the model are used the exact solution of the model can also be given as a sum of a few exponential functions. The corresponding parameters were determined by an eigenvalue analysis and it could be demonstrated that the exact wound retention functions can be given as sums of three exponential functions. Now it is also planned to give the exact input functions to lymph and blood as sums of exponential functions.

Systemic models

It was planned to implement the new biokinetic systemic models being developed by ICRP for the revision of its publications 30$^{(5)}$, 54$^{(6)}$, 68$^{(7)}$, and 78$^{(8)}$ to be able to quality assure also their formulation. However, they were not finalised during the time CONRAD was running. But some new models which may become the new ICRP models have been implemented, for example the polonium model by Leggett and Eckerman$^{(15)}$. Another example was plutonium (Pu) for which the models of ICRP Publication 67$^{(16)}$, of Luciani and Polig$^{(17)}$ and of Leggett *et al.*$^{(18)}$ are designed. All these models were implemented and the numbers of transformations in the compartments involved were calculated. The intercomparison of results again showed excellent agreement, also for the Luciani and Polig model which has age-dependent transfer rates in the skeleton between the ages of 35 and 60 y. This age-dependence was implemented by solvers of differential equations with time-dependent parameters by most groups while the BfS code DOSAGE had a step-wise approach with the assumption of constant parameters for every year. Both approaches showed very good agreement.

The results showed no large differences between the present ICRP model and the model of Leggett *et al.* while the model of Luciani and Polig revealed differences up to a factor of 4 (for example the numbers of transformations in red bone marrow) compared to the present ICRP model. On the other hand the age-dependence of this model does not influence the results very much: The differences between the assumption of an intake at age 25 y compared to 45 y were mostly in the range of 10%.

A tuning parameter for actinides

A part of the work of our group was also to check the biokinetic models for their appropriateness to be used in specific situations. In this connection a tuning parameter for systemic actinide was developed. Actinides are taken up mainly by skeleton and liver but there are substantial individual differences in the uptake ratios. For individual dose assessment therefore a tuning parameter p_{skel} was defined as

$$p_{skel} = \frac{f_{skel}}{f_{skel} + f_{liver}}$$

where f_{skel} and f_{liver} are the initial uptake factors to skeleton and liver, respectively.

This parameter has the values 0.63, 0.77, and 0.33 for the models of ICRP Publication 67(16), Luciani and Polig(17), and Leggett *et al.*(18). However, this value is related to a specific model and it cannot be used for the comparison of models. A sensitivity analysis for p_{skel} performed with the ICRP 67 model indicated significant effects for faecal excretion but almost no effect for urinary excretion. Therefore the faecal to urinary excretion ratio could be a specific indicator for the most appropriate p_{skel} value for the situation considered.

Evaluation of stable isotope studies

Stable isotope studies are a powerful tool to get human data for the development of biokinetic models. Two different stable isotopes are incorporated by ingestion and injection. After that, the amount of these isotopes in blood and urine is measured. From the blood data the f_A value can be derived as well as the absorption velocity which can give a hint to possible wall retention during the absorption process or to absorption also from other alimentary tract compartments than the small intestine. Moreover urinary excretion information can be obtained by the urine measurements.

Information on HATM parameters

Stable isotope studies involving molybdenum (Mo), strontium, ruthenium, and zirconium (Zr) were evaluated. The f_A values derived partly were substantially different from those presently recommended by ICRP. No age- and gender-dependence could be observed for absorption to blood. Moreover, there was no delayed uptake to blood which would be an indication of retention in the gut walls during the absorption process. It could be expected that the blood retention was quite different from that predicted by the present ICRP models because for these elements ICRP uses a very simple default model with a biological half-time of 6 h in blood. A more exact modelling of blood retention was not considered to be essential for dose calculations for occupational radiation protection.

Model development

The information derived from the stable isotope studies was also coupled with additional information derived from literature studies and used for model development. Such models were developed for zirconium(19) and molybdenum(20).

The model for Zr(19) proposes f_A values of 10^{-3} for citrates and $7.7 \cdot 10^{-3}$ for oxalates. These values are broadly in agreement with the f_1 value of $2 \cdot 10^{-3}$ proposed by ICRP for workers(5) but lower than that of 10^{-2} proposed by ICRP for adult members of the public(21). The systemic model proposes an exchange of activity between blood and soft tissues and has an uptake to skeleton where it remains. The ingestion doses calculated with the new model for oxalate are similar to the values calculated with the model of ICRP Publication 56(21) while the doses for citrate tend to be lower due to the lower f_A value. The urinary excretion rates calculated with the new model are lower by at least one order of magnitude compared to those calculated with the ICRP model.

The model for Mo(20) proposes separate fractional absorption values for ingestion with the diet ($f_A = 0.6$) and with liquids ($f_A = 0.9$). They again are in broad agreement with the f_1 value of 0.8 proposed by ICRP for workers(5) for compounds different from sulphides but less than the value of 1 proposed by ICRP for adult members of the public(21). This model provides an additional transfer compartment (exchange compartment additionally to the input fast turnover compartment) and excretion pathways via kidneys to urine and via liver to faeces. Uptake is foreseen in kidney tissues and other tissues with subsequent recycling into blood. With respect to the current ICRP estimates, the effective dose coefficients are not significantly changed: $5.8 \cdot 10^{-10}$ $Sv \cdot Bq^{-1}$ and $7.7 \cdot 10^{-10}$ $Sv \cdot Bq^{-1}$ in case of ingestion with liquids and with diet respectively, as compared to the current values of $7.4 \cdot 10^{-10}$ $Sv \cdot Bq^{-1}$ and $6.1 \cdot 10^{-10}$ $Sv \cdot Bq^{-1}$ for workers and members of the public, respectively. However, significant differences can be observed for selected target tissues, in particular the red marrow and the bone surfaces, since skeleton is no longer considered as a source region.

Model for DTPA decorporation

Another work of the CONRAD TG 5.2 was to initiate the development of a biokinetic model describing the mechanisms of decorporation of actinides by administration of DTPA. It turned out that the interest in this issue was such that a sub-Task Group was established which also includes experts who are not members of the CONRAD project.

Administration of DTPA enhances the urinary excretion rate of Pu by about a factor of 50 and also faecal excretion may be enhanced. The effect of the excretion enhancement can be seen over some days; also a few months are reported. On the other hand, according to ICRP Publication 53(22) and to the evaluation of human data by Stather *et al.*(23), DTPA is almost completely excreted in urine within a day; only about 1% is expected to be excreted with a half-time of 7 d. From a physiological point of view, it may be argued that DTPA binds all Pu in extracellular fluids and does not enter cells but it has direct influence on Pu in the liver.

The modelling process was started by using the systemic biokinetic model of Leggett *et al.*(18) for Pu and the biokinetic model for DTPA compounds of ICRP Publication 53(22). The chelation of Pu and DTPA to Pu-DTPA was assumed to follow the equation

$$\frac{d[Pu-DTPA]}{dt} = K_R \cdot [DTPA] \cdot [Pu]$$

where [Pu-DTPA], [Pu] and [DTPA] are the numbers of molecules or atoms. It was assumed that the chelation takes place in the blood1 and the ST0 (the rapid turnover soft tissues including extracellular fluids) compartments of the Pu model. In the first approach it was assumed that Pu-DTPA behaves biokinetically in the same way as DTPA, however also a faecal excretion was considered.

First applications of this draft model showed that the height of the peak of the urinary excretion after administration of DTPA was determined by K_R which demonstrates that this is a suitable tuning parameter which can be determined from the first urine measurement results. Therefore the present draft model could also be applied successfully to a real decorporation case due to the modelling of the urinary excretion peak. However, repetitions of DTPA administration shortly after the first one in this case showed no effect in the application of the draft model because all Pu available in the blood1 and ST0 compartments was removed and these compartments were not yet substantially re-filled according to the models used. On the other hand, the real case showed continuing high-level excretion rates.

This demonstrates that the present draft model is not yet realistic. So the following questions, for example, have to be answered:

- Where are the Pu-DTPA complexes formed?
- Which biological ligands of Pu are dissociated?
- Is Pu-DTPA stable?
- Are the biokinetics of Pu-DTPA excretion similar to that of DTPA?
- What is the effective duration of the decorporation process?
- Is there a dependency on Ca-/Zn-DTPA dosage, route and form of administration?

Further detailed studies of human contamination cases with well defined uptake and experimental data about Pu-DTPA kinetics will be needed and their results have to be incorporated into the model.

CONCLUSIONS

The work of the CONRAD Task Group 5.2 embraced the whole diversity of the use of biokinetic models in the field of internal dosimetry. Besides the implementation of existing models, this work also included a quality assurance of model formulation which partly led to the elimination of some ambiguities before the final publication of these models. For the assessment of the impact of these models also some guidance for their use was developed, for example the definition of a tuning parameter to adjust systemic actinide models to individual characteristics. The results of stable isotope investigations were evaluated with respect to specific features of the new models, for example with respect to retention in the gut walls or to absorption from lower tracts of the intestine. Based on these stable isotope studies also new biokinetic models for zirconium and molybdenum were implemented, and their results were compared with those obtained by the present ICRP models. Finally, another model development task was started: the development of a biokinetic model for the mechanisms of decorporation of actinides by DTPA.

It turned out that this cooperation was very important for the members of the group because the individual work could be coordinated with others and quality assured. Moreover, this work is very important for accompanying the process of ICRP to develop new biokinetic and dosimetric models for occupationally exposed workers to revise its Publications 30, 54, 68, and 78, to quality assure the model formulation and the calculations of dose coefficients and bioassay data as well as to evaluate the models with respect to their usability.

For these reasons and to be able to complete the development of the DTPA decorporation model, it is considered to be essential that this work will be continued. This continuation will be established within a EURADOS work package and hopefully also within the 7th framework programme of the European Union.

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THE WORK OF THE CONRAD TASK GROUP 5.2: RESEARCH STUDIES ON BIOKINETIC MODELS

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The objective of this Task Group is the coordination of research studies on biokinetic models and the evaluation of the implications of new biokinetic models on dose assessment and safety standards. For this the new ICRP models, which will be used for a revision of ICRP Publications 30, 54, 68 and 78, are implemented into six different computer codes in five European countries and quality assured by intercomparison procedures. The work has started with the implementation of the new ICRP Alimentary Tract Model. New systemic models and the new NCRP wound model will follow. The work also includes the evaluation of experimental results in terms of formulation by the new model structures and a quality assurance of model formulation.

INTRODUCTION

The concerted action 'A Coordinated Network for Radiation Dosimetry' (CONRAD)⁽¹⁾ is funded within the EURATOM 6th Framework Programme for research and training in nuclear energy (contract no. FI6R-012684). The project involves two main activities to maintain and enhance competence in radiation protection dosimetry: It analyses the options for sustainable networks linking research players and end users and it coordinates research concerning measurements and calculations for radiation protection at workplaces. It started at the beginning of 2005 and it has been running for 3 y.

CONRAD is structured into seven Workpackages. The objective of Workpackage 5 'Internal Dosimetry' which is headed by M. A. Lopez is the coordination of research on assessment and evaluation of internal exposures. This Workpackage is sub-divided into five Task Groups including Task Group 5.2 'Research Studies on Biokinetic Models'. Fifteen scientists out of six European countries are working within this Task Group, headed by D. Noßke in order to coordinate research studies on biokinetic models and to evaluate the implications of new biokinetic models on dose assessment and safety standards.

WORK PROGRAM OF TASK GROUP 5.2

ICRP is preparing a revision of its Publications 30(2), 54(3), 68(4) and 78(5) related with internal doses to occupationally exposed workers and their individual monitoring. This revision will include (1) the new ICRP Human Alimentary Tract Model (HATM)(6), (2) individual absorption parameters within the ICRP Human Respiratory Tract Model (HRTM)(7) different from the standard Types F, M and S, (3) new systemic biokinetic models as well as (4) new dosimetric parameters based on voxel models(8) of the ICRP male and female adult reference persons and (5) the new concept of ICRP to calculate the effective dose(9). The aim of the Task Group's work is to evaluate the impact of the applications of new models for dose assessment, e.g. the new HATM, the wound model of the National Council on Radiation Protection & Measurements (NCRP) and new revised systemic models.

Implementation of the HATM

The new ICRP HATM(6) (Fig. 1) was implemented into computational codes by six different groups in five European countries: into the codes (a) of the Federal Office for Radiation Protection (BfS), Germany, and (b) of the Ukrainian Radiation

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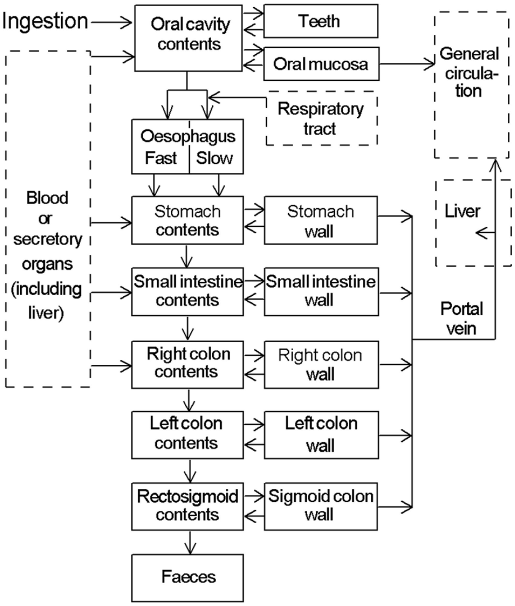

Figure 1. Structure of the ICRP HATM(6).

Protection Institute Kiev which both were also used in ICRP quality assurance procedures as well as (c) into the IMBA code(10) of the British Health Protection Agency, Radiation Protection Division, and into codes of (d) IRSN (France), (e) University of Milan and (f) ENEA Bologna (Italy).

Quality assurance of the model implementation

Quality assurance procedures were started by comparing results of numbers of disintegrations within the compartments of the alimentary tract as well as daily faecal excretion rates for several radionuclides with different half-lives ranging from a few minutes (^{133}Te) to billions of years (^{238}U) and different values of fractions of ingested activity which are absorbed to blood, f_A, ranging from 0.0005 to 0.99. For these calculations it was assumed that—as in the old model(2)—absorption to blood is only from the small intestine without retention in the wall. Examples of results are provided in Table 1.

The comparison of the computational results showed excellent agreement: the discrepancies in the results of numbers of disintegrations calculated by different codes were less than 1%. The discrepancies in the results of the daily excretion rates were a little bit larger than those of the numbers of disintegrations but at the end also did not exceed 1%.

It could also be seen that the application of analytical and numerical, e.g. Runge–Kutta, methods both used by the BfS code DOSAGE showed almost no discrepancies. Only for the very short-lived radionuclide ^{133}Te these were up to 0.2% in the last compartments of the tract. This demonstrates that in spite of the very short transit times of a few seconds in the mouth and oesophagus analytical methods can also be applied for the computations.

The work focussed on quality assurance is being continued with more complicated computational examples including (1) the calculation of nuclear transformations of daughter nuclides produced within the tract with both assumptions of shared or independent f_A values, (2) the consideration of other absorption sites (assuming that for iodine half is absorbed from the stomach and the other half is absorbed from the small intestine) and (3) the evaluation of the impact of retention in the small intestine wall with

Table 1. Number of disintegrations within the compartments of the old ICRP gastro-intestinal model(2) and the new ICRP HATM(6).

Radionuclide	^{133}Te		^{201}Tl		^{238}U	
Half-life	12.45 min		3.044 d		4.468 $\times 10^9$ y	
f_A or f_1	0.3		0.99		0.02	
	Number of nuclear transformations over 50 y					
Compartment	Old	New	Old	New	Old	New
Mouth	NA	1.2E + 01	NA	1.2E + 01	NA	1.2E + 01
Oesophagus	NA	1.0E + 01	NA	1.0E + 01	NA	1.0E + 01
Stomach	8.3E + 02	8.4E + 02	3.6E + 03	4.2E + 03	3.6E + 03	4.2E + 03
Small intestine	2.2E + 02	1.9E + 02	1.4E + 02	1.4E + 02	1.4E + 04	1.4E + 04
Right colon	NA	1.4E + 01	NA	3.8E + 02	NA	4.2E + 04
Upper large intestine	1.6E + 01	NA	4.2E + 02	NA	4.7E + 04	NA
Left colon	NA	3.5E−01	NA	3.4E + 02	NA	4.2E + 04
Lower large intestine	3.6E−01	NA	6.2E + 02	NA	8.5E + 04	NA
Rectosigmoid colon	NA	8.4E−03	NA	3.1E + 02	NA	4.2E + 04

No recycling within the gut walls or absorption to blood from another site than the small intestine is considered here.
NA, not applicable; old, ICRP gastro-intestinal tract model(2); new, ICRP HATM(6).

partly subsequent recirculation into the small intestine contents during the absorption process for ^{59}Fe.

Quality assurance of model formulation

Model implementation work is also a very efficient means of quality assurance for the model description. During the implementation of the HATM, some inconsistencies concerning total and regional absorption fractions were discovered in the draft ICRP text.

In the new HATM, absorption to blood is possible not only from the small intestine contents as in the old gastro-intestinal model(2) but from almost all regions of the tract. Therefore, the fraction absorbed from the tract to blood which was called f_1 in the old gastro-intestinal tract model is now called f_A in the new HATM and this total fraction absorbed to blood may be described by several regional absorption fractions. In the former draft ICRP text and its formulas it was not unambiguous if these regional fractions were related to the amount of intake to the tract (which is the case in the final model, i.e. f_A is the sum of all regional absorption fractions) or if they were related to the amount transferred to the respective absorption sites. Respective comments were directed to the ICRP HATM Task Group and the text and its formulas could be corrected before going into press. It may be noted that, as an effect of this new concept, f_A may now differ for ingested and inhaled material in cases involving absorption from the oral cavity because the intake of inhaled material to the tract takes place beyond the oral cavity into the oesophagus.

Evaluation of stable isotope studies

Additionally, experimental studies using stable isotope techniques were evaluated with respect to possible indications for uptake from sites other than the small intestine or for retention in the gut walls. The assessment of experimental absorption studies for Mo(11) and Sr(12) showed that there seems to be no delayed uptake to blood which would indicate the possibility of absorption from the colon or retention within the gut walls. It seems to be most likely that these elements are absorbed from the small intestine without a substantial delay in its wall.

Future actions

Up to now, most work has been done concerning the HATM, which is a very new model compared with the old gastro-intestinal tract model(2) and which has just been published(6). Other new biokinetic models for the revision of ICRP Publications 30, 54, 68 and 78 will be systemic models and the new NCRP wound model(13) while there seem to be no substantial changes concerning the ICRP HRTM(7).

Human respiratory tract model (HRTM)

No specific work concerning the HRTM(7) has been planned so far. The structure of this model will stay but the ICRP is preparing recommendations of absorption parameters different from the default Types F, M and S if information is available. During that work it has been realised that the parameters for the absorption Types F and S may be too extreme and therefore it might be that the absorption parameters for these Types will be changed. There may also be some updating of particle transport rates from each region based on new information(14). Therefore possibly there will be some calculations in co-operation with the ICRP DOCAL group concerning the effect of changing the clearance parameter values.

NCRP wound model

NCRP has developed a wound model(13) in collaboration with ICRP which will be published soon. It is also a multi-compartmental model with first-order kinetics to describe the retention and clearance of radionuclides from the wound site. There will be default parameters for soluble materials which are retained weakly, moderately, strongly and avidly at the wound site as well as for colloids, particles and fragments. The CONRAD Task Group 5.2 will implement this model and will perform some quality assurance procedures of the implementation by computational checks – similar to the procedure for the HATM.

Systemic models

ICRP has started to revise the systemic biokinetic models. There is a clear tendency towards the development of more realistic, but also more complicated, physiologically based recycling models and towards the consideration of independent daughter kinetics. According to the present drafts, one of the most complicated models is the Cs model which will be based on a blood-flow model—with independent biokinetics for the short-lived daughter ^{137m}Ba of ^{137}Cs. The CONRAD Task Group 5.2 will implement these models and will evaluate the changes compared with the old models as well as the implications of the consideration of independent daughter kinetics.

Another proposal for the Task Group's work is the development of a model to describe the effects of treatment with diethylenetriaminepentaacetic acid (DTPA). Such a model is not currently available, but the need of such a model is recognised even if DTPA treatment may not be very efficient in reducing doses. Although the excretion rate can be enhanced by a factor of 50, the total excreted activity is small compared with that retained. It was decided that data on DTPA treatments will be collected, and that a biokinetic model will be proposed in an iterative process which will be tested against the data.

CONCLUSIONS

The CONRAD Task Group 5.2 is accompanying the process of ICRP to develop new biokinetic and dosimetric models for occupationally exposed workers to revise its Publications 30, 54, 68 and 78. For this, the new models are implemented into different computer codes and these implementations are quality assured within the Task Group. Quality assurance of computer implementations also includes a quality assurance of model formulation by ICRP. Moreover, experimental results are evaluated to understand to what extent they can be described by the new model structures.

Altogether the results of this work are important as a support (a) for on-going efforts of the ICRP Committee 2 Task Group on Dose Calculation to which there is a link by several common members, as well as (b) for the recently initiated process of review of the IAEA Basic Safety Standards.

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Characterisation, implementation and quality assurance of biokinetic models. The experience of the CONRAD Task Group 5.2

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Abstract

CONRAD (Coordinated Network on Radiation Dosimetry) was an action funded by the European Commission within the 6th Framework Programme in order to network groups making research in radiation dosimetry under the coordination of the European Radiation Dosimetry Group EURADOS. Workpackage 5 of CONRAD, headed by Maria Antonia Lopez (CIEMAT, Spain), was dedicated to internal dosimetry. Task Group 5.2 "Research Studies on Biokinetic Models", headed by Dietmar Nosske (BfS, Germany) and composed by scientists out of six European countries, dealt with development, implementation, characterization and quality assurance of biokinetic models.

The new ICRP model of the human alimentary tract (HATM), the new NCRP model for contaminated wounds, new systemic biokinetic models for polonium and plutonium radionuclides, including recycling, presented in the scientific literature were implemented into the computer codes of five different institutions. Also new systemic biokinetic models for zirconium and molybdenum, developed on the basis of own results from stable tracer studies, were implemented.

The excellent agreement among the results obtained by the different groups indicated that all the present models can be easily implemented into available software codes and that the outputs are independent on the computational approach used, also in the case of more complex structures. Therefore it does not seem justified to suggest simplifications of complex models including recycling and/or absorption in the organ walls, as those suggested for example in ICRP Publication 100 for the iron model.

During the work it was also possible to better characterize available models, for examples the systemic models of plutonium on the basis on the partition factor p_{skel} (relative distribution of material between skeleton and liver), or the NCRP wound model, by derivation of the exact analytical solutions for the wound retention and for the input to lymph nodes and blood as resulting from the model formulation.

KEYWORDS: biokinetics, systemic models, wound model, HATM, internal dosimetry.

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Monte Carlo modelling of Germanium detectors for the measurement of low energy photons in internal dosimetry: Results of an international comparison

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Abstract

This communication summarizes the results concerning the Monte Carlo (MC) modelling of Germanium detectors for the measurement of low energy photons arising from the "International comparison on MC modelling for in vivo measurement of Americium in a knee phantom" organized within the EU Coordination Action CONRAD (Coordinated Network for Radiation Dosimetry) as a joint initiative of EURADOS working groups 6 (computational dosimetry) and 7 (internal dosimetry). MC simulations proved to be an applicable way to obtain the calibration factor that needs to be used for in vivo measurements.

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Keywords: Ge detectors; Monte Carlo simulations; Voxel phantoms; Internal dosimetry

1. Introduction

The use of Germanium detectors for direct measurement of the gamma emission from the body is an effective method to assess the radionuclide body burdens in case of internal contamination by low energy gamma emitters (ICRU, 2003). This technique requires the use of the appropriate anthropomorphic phantom with a known distribution of the considered radionuclide to calibrate the detection system. In addition to those physical phantoms, the combined use of numerical voxel phantoms and Monte Carlo (MC) methods to simulate radiation transport and detection is becoming an increasingly used alternative (Zankl et al., 2003; Gómez Ros et al., 2007a).

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Table 1
List of participants in the international comparison (ordered by institutions in alphabetical order)

Institution/laboratory	Participants	Country
AWE, Dosimetry and Radiology Metrology Services	L.W. Packer	UK
CIEMAT	J.M. Gómez-Ros, M. Moraleda and M. Lis	Spain
ENEA	P. Ferrari and G. Gualdrini	Italy
Forschungszentrum Karlsruhe GmbH	B. Heide	Germany
Human Monitoring Lab	G.H. Kramer and K. Capello	Canada
Institute of Radiation Dosimetry	J. Hunt	Brazil
INTE, University of Barcelona	J. Sempau and A. Badal	Spain
IRSN	B. Zhang, L. de Carlan and D. Franck	France
Japan Atomic Energy Agency	S. Kinase	Japan
LARN Laboratory, University of Namur	V. Nuttens and S. Lucas	Belgium
National Radiation Protection Institute	T. Rvba	Czech Republic
Serco Assurance	P. Cowan and V. Hooley	UK
Technical University of Dresden	J. Henniger, U. Reichelt and D. Löhnert	Germany

Both in the experimental and in the numerical calibration, the calibration factor should be determined in a well-defined geometry using a phantom that adequately reproduces the human form and the distribution of the radionuclide. When the emission spectrum consists of single or well-separated peaks, as it is the case of ^{241}Am (Wahl, 2006), the region of interest (ROI) method is commonly used (ICRU, 2003). In such a method, the peak efficiency at a given energy is defined as the ratio of the number of detected photons within a given energy range around the main energy emission (i.e. the area of the corresponding peak of the spectrum), normalized to the activity of the source in terms of count rate per Bq (cps Bq^{-1}).

With the purpose of studying the capabilities of different MC codes and the variations in the results when different approaches are applied to simulate an experimental in vivo measurement of ^{241}Am in bone, an "International comparison on MC modelling for in vivo measurement of Americium in a knee phantom" (Gómez-Ros et al., 2007b) has been co-organized by CIEMAT (Spain), IRSN (France), ENEA (Italy) and GSF (Germany) within the EU Coordination Action CONRAD (Coordinated Network for Radiation Dosimetry), partly supported by the Sixth Framework Programme.

In the case of ^{241}Am, only the highest energy and most significant gamma emission at 59.54 keV (35.9% yield) is usually considered for calibration purposes in routine in vivo measurements. Nevertheless, and although it is only the corresponding peak efficiency that use to be employed, previous results (Ménard, 2004) already indicate that significant differences in the scattered contribution to the pulse-height spectrum can be found depending on the transport models considered for the simulations. For this reason, two criteria were employed to compare the results provided by the participants in the comparison with the reference experimental measurement (Gómez-Ros et al., 2007b): (a) the complete pulse-height spectrum in the region 5–70 keV and (b) the peak efficiency at 59.54 keV (ROI: 57.7–64.4 keV).

Thirteen laboratories and research groups (Table 1) of 10 countries from Europe, America and Japan participated in this initiative, providing 14 solutions (each group run a single code but one of them that performed two different simulations). The details about the MC codes and cross-section libraries used for each of the proposed solutions are listed in Table 2 where they have been labelled by letters from (a) to (n) in order to preserve the anonymity of each contributions. Although some preliminary tasks concerning the calibration of the detectors using an ^{241}Am source and the analysis of the photon fluence distribution around the knee phantom were also performed, only the results concerning the calibration measurement on the knee phantom are discussed in detail in this paper.

Table 2
List of Monte Carlo codes used for each of the proposed solutions

Solution	MC code	Photon library	Electron library
(a)	AMOS-PE	EPDL	EEDL
(b)	EGS4-UCWBC	PHOTX	ICRU-37
(c)	MCBEND v10A	DICE	MCBEND
(d)	MCNP4c2	mcplib02	el03
(e)	MCNP5	mcplib03	el03
(f)	MCNP5	mcplib04	No electron transport
(g)	MCNPX 2.5	mcplib04	el03
(h)	MCNPX 2.5	mcplib02	el03
(i)	MCNPX 2.5	mcplib02	el03
(j)	MCNPX 2.5	mcplib04	No electron transport
(k)	MCNPX 2.5	mcplib04	el03
(l)	MCNPX 2.5	mcplib04	el03
(m)	PENELOPE	EPDL	ICRU-37
(n)	VMC	NIST	No electron transport

2. Materials and methods

2.1. Ge detection system

The detection system consisted of a pair of Canberra Low Energy Germanium detectors (LE Ge) mounted in an ACTII cryostat. Each detector contains a germanium crystal 25 mm thick and 70 mm in diameter. An entrance window made of carbon fibre and epoxy resin of thickness 0.6 mm is separated from the Ge crystal by a 5 mm vacuum gap. The detectors and

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the calibration phantom to be measured were placed inside the shielded room of the CIEMAT whole body counter (López and Navarro, 2000).

The modelling of the detectors for the MC simulation has been based on the technical specifications provided by the manufacturer and the parameters for the Gaussian energy broadening empirically determined (Gómez-Ros et al., 2007b). To prevent discrepancies usually found when using manufacturer's nominal value for the thickness of the Ge dead layer (Clouvas et al., 1998), such value has been adjusted by comparison of the measured and simulated detection efficiencies for a calibration ^{241}Am source located 30 cm from the detector along the main axis.

2.2. The anthropometric knee phantom and the knee voxel phantom for MC simulations

The Spitz anthropometric knee phantom (Spitz et al., 2000; Spitz and Lodwick, 2000) is an accurate model of a human left knee made in a polyurethane-based substitute for muscle tissue and a similar polyurethane-based material adjusted to the calcium content of trabecular bone by addition of a 33% in weight of $CaCO_3$ (Spitz and Lodwick, 2000). During fabrication, a given activity of ^{241}Am has been uniformly incorporated to the bone material in order to use the phantom for calibration of in vivo measurement of Americium in the knee.

For the MC simulations, a knee voxel phantom has been built based on a computerized axial tomography (CAT) of the Spitz knee phantom described above (Gómez-Ros et al., 2007b). The original images stack was first shrunk to a stack of 75 slices by excluding those slices at the beginning and at the end of the stack partially shaded due to the flexion angle of the phantom and then processed by automatic thresholding segmentation and filtering to distinguish air and bones from muscle tissue. Finally, pixel spacing have been rescaled to 2 mm to produce a voxel phantom with three materials (air, muscle tissue, bone) and voxel size $2 \times 5 \times 2\,\text{mm}^3$.

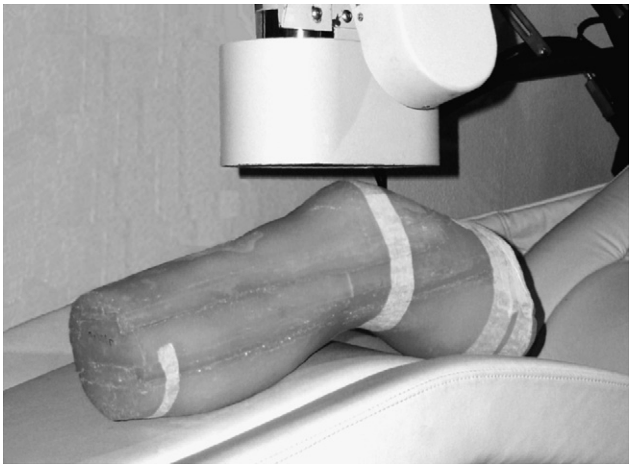

Fig. 1. Detection system consisting of a pair of Canberra LE Ge detectors mounted in an ACTII cryostat measuring the activity of the calibration Spitz anthropometric knee phantom.

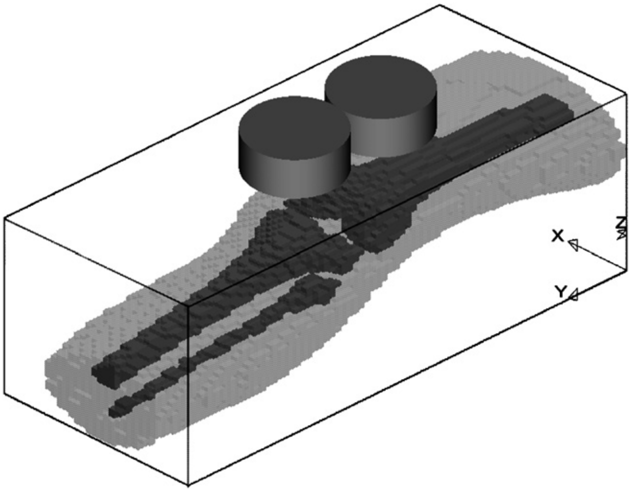

Fig. 2. Axonometric 3D view of the pair of LE Ge detectors located above the knee voxel phantom to calculate pulse-height spectrum and peak efficiency.

3. Results and discussion

A simple and reproducible counting geometry with the two Ge detectors vertically located above the knee phantom was employed for the experimental measurements (Figs. 1 and 2). The relative positions were determined with photographs and all the geometric specifications were provided to the participants together with voxel phantom data (both the original images files and the segmented data in ASCII format).

Fig. 3 shows the 14 simulated pulse-height spectra obtained using the MC codes listed in Table 2, compared with the measured results. As it can be seen, the simulated pulse-height spectra reproduce very closely the shape of the main peak at 59.54 keV as well as the region above 30 keV, thus indicating the accurate modelling of scattered photons in the voxel phantom. For the lower energy peaks at 17.61, 21.00 and 26.35 keV, all the codes tend to produce slightly narrower peaks and a certain underestimation in the region between peaks. This effect does not affect the peak efficiency regions and it is mainly related to the electron transport models considered by the different MC codes (Ménard, 2004). Detailed transport models (e.g. Penelope code, Fig. 3m) provided a better agreement with the experimentally measured spectrum than those simulations based on the kerma approximation (e.g. Figs. 3f and n) when local deposition of the energy transferred to secondary electrons has been assumed.

The calculated peak efficiency values at 59.54 keV corresponding to each of the 14 solutions are shown in Table 3 and Fig. 4 that compares such values (dots) with the experimental result (solid line). The calculated values (average: $3.74 \times 10^{-3}\,\text{cps}\,\text{Bq}^{-1}$, standard deviation: 2.6%) systematically overestimated the measured one, $3.56 \times 10^{-3}\,\text{cps}\,\text{Bq}^{-1}$, by a 1–8%. To investigate the origin for this discrepancy, some additional MC simulations were performed considering small variations in the position and angles of the detectors around the reference measurement position in order to calculate the uncertainty in

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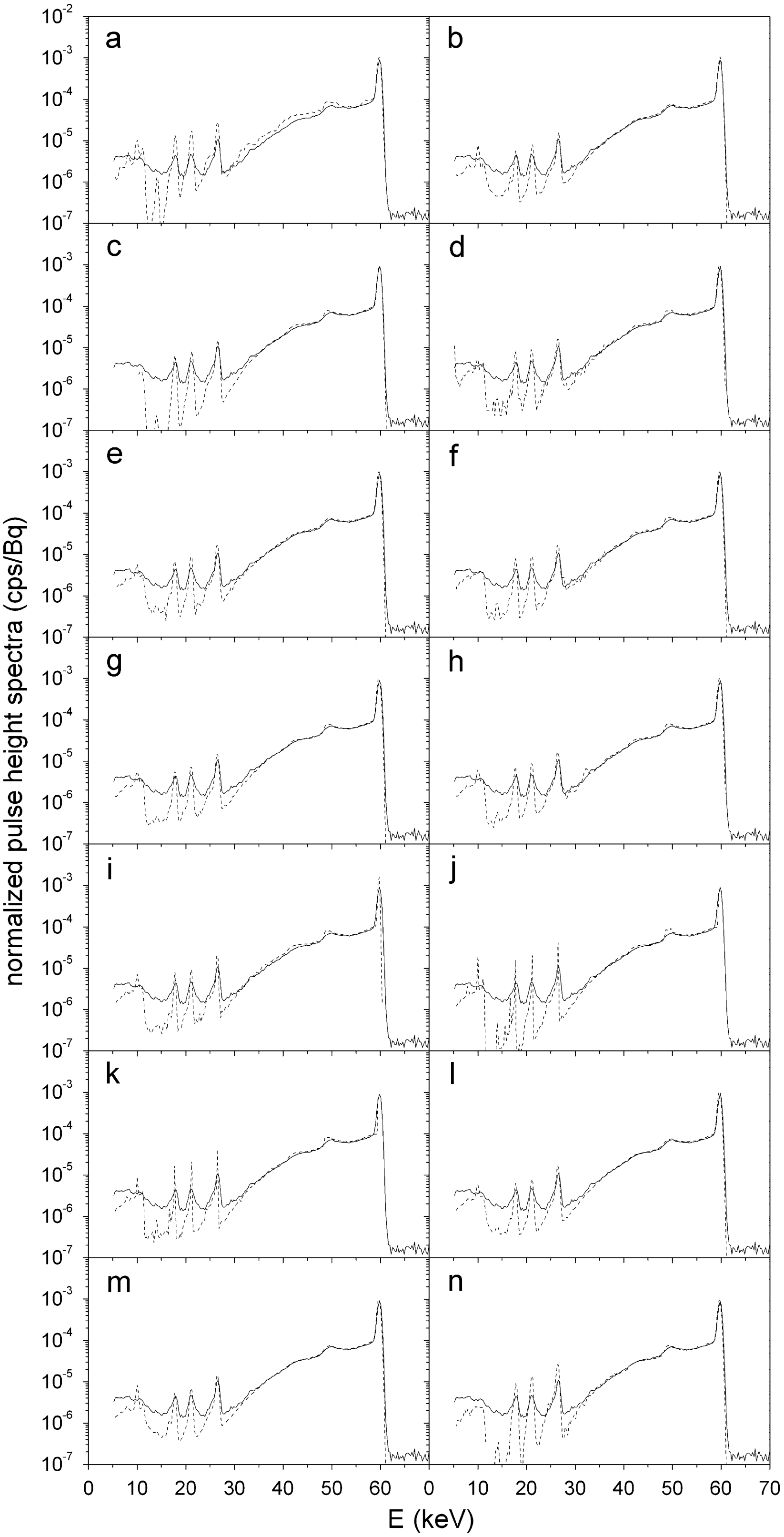

Fig. 3. Comparison of the pulse-height spectrum of ^{241}Am, measured in the pitz knee phantom with the two LE Ge detectors (solid line) and simulated (dashed line) with the corresponding knee voxel phantom and different Monte Carlo codes, listed in Table 2.

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Table 3
Calculated peak efficiency at 59.54 keV for the simulated pulse-height spectra depicted in Fig. 3

Solution	Peak efficiency at 59.54 keV (cps Bq^{-1})
(a)	3.84×10^{-3}
(b)	3.66×10^{-3}
(c)	3.59×10^{-3}
(d)	3.86×10^{-3}
(e)	3.81×10^{-3}
(f)	3.67×10^{-3}
(g)	3.70×10^{-3}
(h)	3.75×10^{-3}
(i)	3.60×10^{-3}
(j)	3.80×10^{-3}
(k)	3.80×10^{-3}
(l)	3.89×10^{-3}
(m)	3.69×10^{-3}
(n)	3.64×10^{-3}

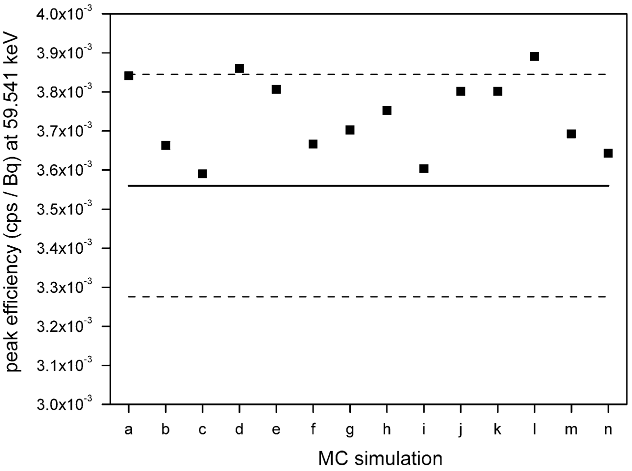

Fig. 4. Peak efficiency at 59.541 keV. Solid line is the measured value and dots correspond to the calculated values by the participants. Dashed line represents a 8% uncertainty around the measured value, due to the inaccuracy in the positioning of the detectors (see Table 4 and discussion in the text).

Table 4
Uncertainties due to positioning of the detectors

Parameter	Position	Range of variation	Std. uncertainty
x (lateral displacement)	7 cm	±1 cm	1%
y (longitudinal displacement)	15 cm	±1 cm	2%
z (vertical displacement)	24 cm	±1 cm	7%
θ_X (lateral angle x-direction)	0°	±5°	≈ 0
θ_Y (longitudinal angle y-direction)	0°	±5°	1%

the measurement arising from the inaccuracy in the positioning of the detectors. As it can be seen in Table 4, largest contribution is due to the vertical displacement (distance from the detector to the knee phantom), resulting in a combined uncertainty of 8% that can explain the systematic differences found between calculated and measured values. In particular, it is interesting to remark that a code without simulation of the transport of secondary electrons (solution n: Visual MC) provided a value for the calculated efficiency in good agreement with the experimentally measured.

4. Conclusions

The simulation of the pulse-height spectrum in the Ge detectors proved to require a detailed knowledge of the complete specifications in order to accurately reproduce the experimentally measured values. This involved not only dimensions, materials composition and densities of the elements in the detectors but a realistic modelling of the calibration phantom. Once some previous errors concerning voxel phantom implementation and source sampling made by some of the participants were fixed, all the considered MC codes reproduce well the experimental pulse-height spectrum above 30 keV, although the scattered contribution between peaks below 30 keV tends to be underestimated.

The agreement between the calculated peak efficiencies and the measured value is consistent with the uncertainty associated to small variations in the positioning of the detectors, thus confirming that peak efficiency can be significantly affected by changes in the relative position of the detection system. From a practical point of view, even much higher differences can be expected from anatomical variations between actual individuals, so an extremely accurate calibration using a phantom (either physical or mathematical) would not be actually required for the purpose of assessing internal contamination by in vivo measurements in a whole body counter.

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International Comparison on Monte Carlo Modelling for *In Vivo* Measurements of Americium in a Knee Voxel Phantom

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M. A. López [2,a] M. Moraleda[2] and M. Zankl[5,a]**

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[a] CONRAD-WP5
[b] CONRAD-WP4

CONTEXT

This communication summarizes the main points concerning the "International comparison on MC modelling for in-vivo measurement of Americium in a knee phantom" organized within the EU Coordination Action CONRAD (Coordinated Network for Radiation Dosimetry), partly supported by the Sixth Framework Programme (Contract no. FP6-12684). The analysis is in process and will be based on fifteen numerical simulations of a real in-vivo measurement of ^{241}Am in a knee phantom, provided by thirteen laboratories of ten countries around the word that participated in this initiative.

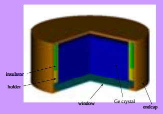
Participants

	Institution / Laboratory	Participants	Country
1	AWE, Dosimetry and Radiol. Metrology Services	L.W. Packer	U.K.
2	CIEMAT	J.M. Gómez-Ros, M. Moraleda and M. Lis	Spain
3	ENEA	P. Ferrari and G. Gualdrini	Italy
4	Forschungszentrum Karlsruhe GmbH	B. Heide	Germany
5	Human Monitoring Lab	G.H. Kramer and K. Capello	Canada
6	Institute of Radiation Dosimetry	J. Hunt	Brazil
7	INTE, Univ. Barcelona	J. Sempau and A. Badal	Spain
8	IRSN	B. Zhang*, L. de Carlan and D. Franck	France
9	Japan Atomic Energy Agency	S. Kinase	Japan
10	LARN Laboratory, Univ. of Namur	V. Nuttens and S. Lucas	Belgium
11	National Radiation Protection Institute	T. Rvba	Czech Republic
12	Serco Assurance	P. Cowan and V. Hooley	U.K.
13	Techn. Univ. Dresden	J. Henniger, U. Reichelt and D. Löhnert	Germany

*CIRP: China Institute for Radiation Protection

MATERIALS AND METHODS

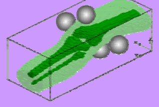
TASK 1: Energy distribution of pulses and peak detection efficiency in a single LE Ge detector, for a point ^{241}Am source



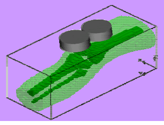
E (keV)	yield
13.93	0.132
17.61	0.1861
21.00	0.0482
26.35	0.024
59.541	0.359

Gamma emissions of ^{241}Am
(W. Wahl *Radionuclide Handbook*, ISUS 2006)

TASK 2: Energy distribution of photon fluence, Φ_E, around the knee phantom, due to a homogeneous distribution of ^{241}Am in bone



TASK 3: Energy distribution of pulses and peak detection efficiency in a pair of LE Ge detectors, due to a homogeneous distribution of ^{241}Am in bone



The detection system consisting of two Canberra Low Energy germanium detectors (LEGe) has been simulated according to the technical specifications provided by the manufacturer. In addition, a knee voxel phantom representing a human left knee has been built based on a computerized axial tomography of the Spitz anthropometric knee phantom. The participants have been asked to deal with the simulation of in vivo monitoring of 241Am in the knee using their Monte Carlo codes and the knee phantom and detectors described above. The comparison has been focused on three specific aspects:

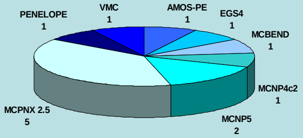
1. Simulation of a single LEGe detector for a point 241Am source in air.
2. Calculation of the photon fluence spectra in air spheres around the voxel phantom, due to a homogeneous distribution of 241Am in bone.
3. Calculation of the energy distribution of pulses and peak detection efficiency in a two LE Ge detectors system due to a homogeneous distribution of 241Am in bone.

PREMILINARY RESULTS

Special attention has been paid to the critical analysis of similarities and discrepancies, both among the different numerical solutions and comparing these with the experimental results (in cases 1 and 3), arising from the different MC codes and models used to simulate photon/electron transport and interaction processes in the range 10-60 keV.

The preliminary analysis shows that most of the solutions reproduce pretty well the shape and the area of the main peak at 59.541 keV and also the region above 30 keV. For the low energy peaks, all the codes tend to produce narrower peaks and underestimation in the regions between peaks. A possible explanation could be the fine structure of this peak. Other aspects specifically related with photon and electron transport at this energies (10-30 keV) will be also considered in the final analysis

Updated information is available in the website: http://www.eurados.org/



Monte Carlo Codes

Intercomparison on Monte Carlo modelling for in vivo measurements of Americium in a knee phantom

Institut de Radioprotection et de Sûreté Nucléaire,
Siège social
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Standard +33 (0)1 58 35 88 88
www.irsn.org

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Radiation Protection Dosimetry Advance Access published September 11, 2007

Radiation Protection Dosimetry (2007), pp. 1–4 doi:10.1093/rpd/ncm403

MONTE CARLO MODELLING FOR IN VIVO MEASUREMENTS OF AMERICIUM IN A KNEE VOXEL PHANTOM: GENERAL CRITERIA FOR AN INTERNATIONAL COMPARISON

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[5]GSF — National Research Center for Environment and Health, D-85764 Neuherberg, Germany

The general criteria and the scientific approach adopted for an 'International comparison on Monte Carlo modelling for *in vivo* measurement of Americium in a knee phantom' that is being organised within the EU Coordination Action CONRAD (Coordinated Network for Radiation Dosimetry) are described her. Detection system and a knee voxel phantom based on a computerised axial tomography of the Spitz anthropometric knee phantom with a homogeneous distribution of ^{241}Am in bone have been considered for the simulation of three specific situations: (a) a single Low Energy Germanium detector for a point ^{241}Am source in air; (b) the calculation of photon fluence spectra in air around the voxel phantom; and (c) the calculation of the energy distribution of pulses and peak detection efficiency in the real detection system geometry.

INTRODUCTION

The combined use of voxel phantoms and Monte Carlo (MC) techniques for *in vivo* assessment of internal radionuclide body burdens has become an increasingly interesting topic in the scientific literature during the last years(1). Within the wide range of applications, both for the assessment of occupational and public exposures(2,3), the direct measurement in the knee is an effective technique to assess the skeletal activity of americium (^{241}Am) and other bone seeking radionuclides that emit low-energy photons(3).

In order to analyse the variations in the results when different approaches are applied to simulate a real experimental situation, an 'International comparison on MC modelling for *in vivo* measurement of Americium in a knee phantom' is being organised. This comparison is a joint initiative of working packages 4 (WP4: computational dosimetry) and 5 (WP5: internal dosimetry) of the EU Coordination Action CONRAD (Coordinated Network for Radiation Dosimetry), partly supported by the Sixth Framework Programme (Contract no. FP6-12684). In the following, the scientific basis and the fundamental requirements lying behind this initiative are be presented.

MATERIALS AND METHODS

Detectors and counting geometry

The detection system used for the measurements consists of a pair of Canberra Low Energy Germanium detectors (LE Ge) mounted in an ACTII cryostat. Each detector contains a germanium crystal 25 mm thick and 70 mm in diameter. An entrance window made of carbon fibre and epoxy resin of thickness 0.6 mm is separated from the Ge crystal by a 5 mm vacuum gap. The detectors and the calibration phantom to be measured were placed inside the shielded room of the CIEMAT whole body counter(4).

To permit an accurate simulation of the detectors, complete details about materials, densities and sizes have been specified according to data supplied by the manufacturer, as it is depicted in Figure 1. Moreover, the front dead layer thickness has been recalculated for each detector by comparing the simulated and the experimentally measured detection efficiencies for a point ^{241}Am source located at 30 cm from the detector along the main axis. Starting with the nominal value (which is almost negligible), the dead layer thickness was modified until an agreement within 6% between experimental and simulated values is obtained. The obtained values are actually higher than the nominal dead layer thicknesses provided by the manufacturer(5).

Knee voxel phantom

A knee voxel phantom representing a human left knee has been built based on a computerised axial tomography (CAT) of the Spitz anthropometric knee phantom(6,7) (Figure 2a and b). The original images stack (rows: 512, columns: 512, slice thickness:

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5 mm, pixel spacing: 0.53125 mm, colour depth: 12 bit gray) have been processed by automatic thresholding segmentation and filtering(8) to distinguish air and bones from muscle tissue. Then, pixel spacing has been rescaled to 2 mm to produce a voxel phantom with three materials (air, muscle tissue, bone) and voxel sizes: $\Delta x = 2$ mm, $\Delta y = 5$ mm (slice spacing) and $\Delta z = 2$ mm (Figure 2c).

Pulse height spectrum, Gaussian energy broadening and peak efficiency

The output of the detection system(4) is connected to a multichannel pulse height analyzer to acquire the energy spectrum, thus consisting of 4096 channels that accumulate those counts which fall within each channel. Energy calibration is performed by using the appropriate sources emitting gamma rays of known energies to compare each measured peak position with the corresponding energy(9). Then, energy binning for the simulation of the spectra were chosen accordingly to the energy width of the analyzer's channel.

Gaussian energy broadening is taken into account using the usual energy dependence of the full width at half maximum (FWHM) of the photoelectric peaks:

$$\mathrm{FWHM}(E) = a + b\sqrt{E} \tag{1}$$

where a and b are empirical constants(9)

Detection efficiency is defined as the ratio of the number of detected photons to the activity of the radioactive source(3). Both the measured and calculated pulse height spectra are normalised to ^{241}Am activity on the phantom to get the results in terms of count rate per Bq (cps Bq^{-1}). The normalised pulse height distribution provides the energy dependence of the detection efficiency. Peak efficiency at the energy of the main gamma emission (59.5 keV) would be calculated as the sum between the two limits of the region of interest.

GENERAL CRITERIA AND SCOPE OF THE INTERNATIONAL COMPARISON

The main purpose of this international comparison is to propose the simulation of a real *in vivo* assessment of ^{241}Am in a knee phantom, with experimental values that can be compared with the simulated ones. Specifically, the measurement of ^{241}Am in a knee phantom using LE Ge detectors has been selected because it permits a realistic but not excessively complex counting geometry, including the complete specification of the detection system and the knee voxel phantom. To evaluate and analyse the possible discrepancies in the results, a graded formulation of the problem has been agreed.

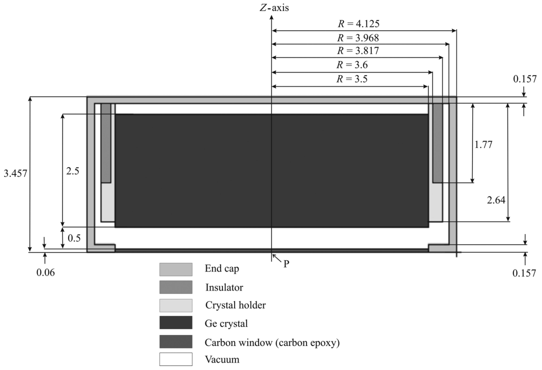

Figure 1. Cut view of the Canberra LE Ge Detector with dimensions (in cm) and materials. The detector has cylindrical symmetry around the *Z*-axis and point P (on the centre of the external surface of the carbon window) is directed towards the source.

Efficiency calibration and pulse height spectrum in a single LE Ge detector for a point ^{241}Am source

Previously obtained results(10) demonstrated that significant differences in the simulated pulse height spectra can be expected just depending on the MC code (i.e. the transport models and the implicit approximations) used for the simulations. To simplify the geometry, the measurement of a ^{241}Am point source at a distance $d = 5$ cm from the centre of the carbon window of the detector (point P in Figure 1) along its main axis has been considered. Then, it has been asked to simulate: (a) pulse height distribution in the active Ge region for the energy binning corresponding to the multichannel analyzer actually employed in the experimental measurements; (b) peak efficiency at 59.5 keV.

Photon fluence spectra around the knee voxel phantom due to a homogeneous distribution of ^{241}Am in bone

A simulation to characterise the spatial variation of the energy distribution of fluence around the knee phantom has been proposed(11). Although experimental data are available for this calculated distribution, it provides information about whether or not the use of different MC codes to implement the voxel phantom (available to the participants both as segmented images and ASCII data files) affects the calculation of the fundamental quantities characterising the radiation field around the phantom. To avoid ambiguity in the geometrical description, voxels positions have indicated by indexes (i, j, k) referring to the left, top, rear corner of the phantom, which corresponds to voxel (1,1,1) (see Figure 3).

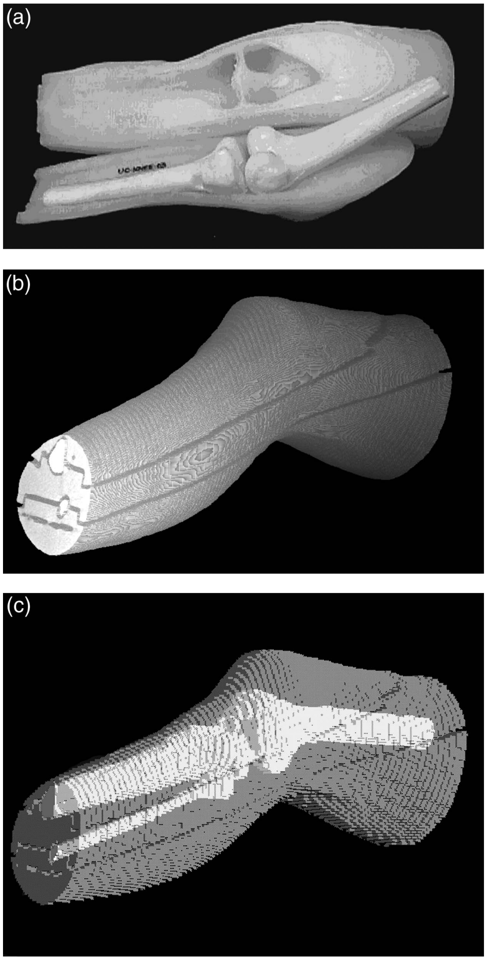

Figure 2. The Spitz anthropometric calibration phantom: (a) physical phantom; (b) renderized 3-D view of the CAT; (c) corresponding voxel phantom $2 \times 5 \times 2\ \text{mm}^3$ voxel size (the *Y*-axis is directed along the leg).

Then, a ^{241}Am source uniformly distributed in the bone tissue of the knee voxel phantom should be considered to calculate the fluence rate spectrum, $\dot{\Phi}$ in four air spheres of radius $R = 3.5$ cm, centred at four positions surrounding the knee, normalised in terms of fluence rate/activity ($\text{m}^{-2}\ \text{s}^{-1}$ per Bq).

Efficiency calibration and pulse height spectrum in a two LE Ge detectors system for a knee phantom with a homogeneous distribution of ^{241}Am in bone

Once possible discrepancies among the solutions provided by the participants have been identified in the simulation of either the detector or the knee phantom, the actual *in vivo* measurement should be simulated and compared with the experimental result. In order to avoid undesired difficulties arising from too complex a counting geometry that may require the specification of angles in space, a simple arrangement with two vertical detectors located on the knee (along the *Z*-axis, according to the reference system adopted for the voxel phantom) has been chosen (see Figure 4). As for the case of a point source and a single detector, pulse height distribution in the active Ge region of the detection system and peak efficiency at 59.5 keV are going to be simulated and compared with one reference measurement.

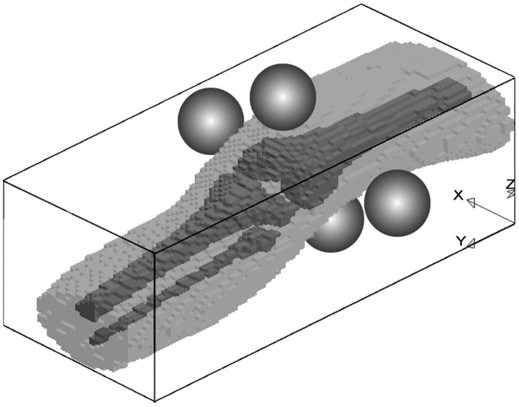

Figure 3. Axonometric 3-D view of four imaginary air spheres around the knee voxel phantom to investigate directional dependence of the energy distribution of fluence.

CONCLUSION

The international comparison described above implies a greater complexity compared with previous initiatives(12,13) where experimental data were not

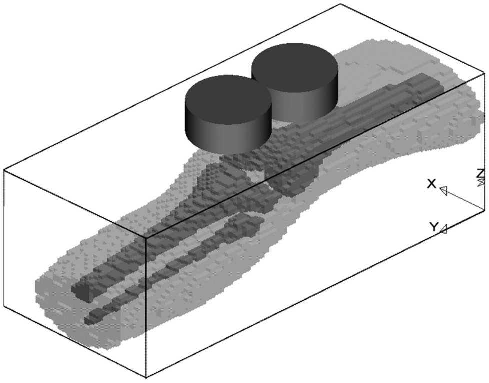

Figure 4. Axonometric 3-D view of the pair of LE Ge detectors located above the knee voxel phantom to calculate pulse height spectrum and peak efficiency.

considered and a more simple geometry was assumed (point source instead of a voxel phantom)(10). Now, the pulse height spectra and peak efficiency values calculated using different MC codes are going to be compared with the reference measurement they simulate. A segmented voxel phantom based on the Spitz anthropometric phantom used in the measurements has been provided to the participants together with the complete specifications. Nevertheless, other questions like the simultaneous comparison of experimental and simulated values and the influence of the segmentation process, starting directly with the original CAT images remain open and may be the subjects of further actions.

ACKNOWLEDGEMENTS

The authors also wish to thank Dr Luis Nuñez (Hospital Puerta de Hierro, Madrid, Spain) for his assistance to perform the CAT of the Spitz knee phantom and Dr Henry B. Spitz (University of Cincinnati, USA) for the detailed information provided about the knee anthropometric phantom.

FUNDING

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A European network of experts directly responsible for monitoring and assessment of doses after deliberate exposure to ionizing radiation

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[5]EDF, Division Ingénierie Nucléaire,Electricité de France at Becquerel, 6, rue ampere, 93203 Saint Denis Cedex,France
[6]CIEMAT, Internal Dosimetry, Avda Complutense 22, 28040 Madrid, Spain

Introduction

In the event of an accidental or deliberate release of radionuclides to the environment, individual monitoring and dose assessment may be needed for large numbers of people. Those needing medical treatment, probably a much smaller number, have to be identified and others need to be informed and reassured. The affected population would include both members of the public and emergency workers responding to the incident. The event could be an accidental release of radionuclides (e.g. a reactor accident) or a deliberate release (e.g. a terrorist incident involving a radiological dispersion device (RDD)). The consequences of such incidents are not limited by national boundaries. However, within the European Union (EU), there is no coordinated strategy for individual monitoring and dose assessment and little exchange of information.

CONRAD (**CO**-ordinatio**N** Action for **RA**diation **D**osimetry) is an EC 6th Framework Programme Co-ordination Action sponsored by EURADOS (the European Radiation Dosimetry Group (http://www.eurados.org). Task 5.4 of the CONRAD project was to establish the EUREMON network, which aims to promote sharing of information between countries on plans and arrangements for individual monitoring. Simultaneously there is a project TMT Handbook -Triage, Monitoring and Treatment of people after malevolent exposure to ionizing radiation.

Establishing the network

The network was given the acronym EUREMON; **EUR**opean **E**mergency **MON**itoring. It was decided that the network should include people with direct responsibility for monitoring and dosimetry of people affected as a result of an incident involving either the accidental release or the malevolent use of radiation or radioactive materials. Invitations were sent to selected people in Europe known to be active in the area of interest.

The stated aims of the network are to collect and share information on: relevant national legislation; any international agreements or existing collaborations relating to monitoring and dose assessment; publications & reports describing strategies for internal and external contamination monitoring; publications & reports giving advice on therapy; equipment for internal/external contamination monitoring after accidental or deliberate releases; current dose assessment methodologies; and currently-available dose assessment software.

Survey of current practice

The survey of current practice was carried out by means of a questionnaire which was developed in such a way that it would meet the needs of both the CONRAD and TMT Handbook projects. It was decided to ask a limited number of questions, but to make them open questions so the recipient would have freedom to give more or less information on a particular topic, as appropriate. To make clear the type of material required, example responses to each question were provided within the body of the questionnaire. Recipients were invited to reply by providing references or copies of existing published documents, and/or by providing a brief written response to each question.

European Radiation Dosimetry Group
EURADOS

Health Protection Agency

TMT Handbook

STUK Radiation and Nuclear Safety Authority

Monitoring, management and treatment of members of the public and emergency workers after accidental or deliberate releases of radionuclides or exposure to radiation

Purpose of this questionnaire

This is a request for information on the current status of arrangements for the triage [1], monitoring [2] and treatment of members of the public and emergency workers after accidental or deliberate [3] releases of radionuclides or exposure to radiation. Topics of interest to us include national strategic plans, monitoring strategies, availability of monitoring resources, capabilities for the interpretation of monitoring data, recommendations on medical management, relevant national emergency exercises, and research and development projects aimed at improving capabilities in this area.

How the information will be used

The information will be used in two 6th Framework Programme projects part-funded by the European Commission:

TMT HANDBOOK (*http://www.tmthandbook.org*) will provide a practicable handbook for the effective and timely Triage, Monitoring and Treatment (TMT) of people following a malevolent act. This is a Specific Targeted Research Project. (Contract no: FP6 - 036497)

CONRAD (Task 5.4) aims to collect and share information on the topics listed above, and also aims to define needs for research, advice and training. This is a Co-ordination Action sponsored by EURADOS (European Radiation Dosimetry Group). (Contract no: FP6 - 12684)

The information you provide will make a valuable contribution to both projects. Individuals, organisations or countries providing information will not be identified in any reports or publications issued unless permission is explicitly given.

What to do now

You only need to answer those questions that are within your area of expertise. Please enter your responses in the fields shaded in light grey. The preferred language is English. Please return the completed questionnaire by e-mail to: peter.pellow@hpa.org.uk. Alternatively, you may fax it to the Health Protection Agency, for the attention of Dr P G D Pellow (++44 1235 833891).

Thank you for your assistance.

Explanatory notes

1. “Triage” – the use of simple procedures to prioritise people rapidly for further actions, including monitoring and treatment, in order to maximise the effective use of resources.
2. “Monitoring” – measurements of external radiation fields, external contamination or internal contamination; and the interpretation of such measurements in terms of radiation doses to the individual. The use of cytogenetics for biological dosimetry is included. The various types of monitoring are referred to generically as “emergency personal monitoring”.
3. That is, the malevolent use of radioactive material in a public place.

TABLE 1 Organisations participating in CONRAD Task 5.4

Organisation	Country	Full / Corresponding Member	Participants	Notes
HPA	United Kingdom	Full	George Etherington Peter Pellow Alan Hodgson Neil Stradling	 From January 2006 Till January 2006
STUK	Finland	Full	Tua Rahola Maarit Muikku	
ENEA	Italy	Corresponding	Paolo Battisti	
CEA	France	Corresponding	Philippe Bérard	
IRSN	France	Corresponding	Cecile Challeton-de-Vathaire	
EdF	France	Corresponding	Bernard Le Guen	
NRPA	Czech Republic	Corresponding	Irena Malatova	

TABLE 2 TMT HANDBOOK participants contributing to the development of the questionnaire

Name of Organisation	Abbreviation	Organisation location
Belgian Nuclear Research Centre	SCK•CEN	Belgium
Norwegian Radiation Protection Authority	NRPA	Norway
Enviros Consulting Ltd.	Enviros	United Kingdom
Radiation and Nuclear Safety Authority	STUK	Finland
Health Protection Agency	HPA	United Kingdom
World Health Organisation	WHO	Geneva
Central Laboratory for Radiological Protection	CLRP	Poland

Section A requests the name and address of the person completing the questionnaire and the organisation to which they are affiliated.
Section B asks the person replying to provide details (i.e. name, address, organisation and expertise) of people within their country who would have direct responsibility for monitoring or management of those people exposed to radiation as a result of an incident; and references and/or internet addresses (uniform resource locators (URL)) for any existing networks relating to the monitoring or management of people after an exposure.
Sections C-L requests information, including references to supporting papers or electronic documents where available, on both theoretical and practical topics that would need to be addressed in dealing with a radiation incident. Where appropriate, a brief description and/or examples of the type of information requested are included at the beginning of the section to help the responder.
The section headings for C-L are:
Section C: Organisations and responsibilities
Section D: Relevant legislation, guidance, international agreements, etc
Section E: Recommendations on monitoring strategies
Section F: Equipment and facilities for emergency personal monitoring
Section G: Recommendations on methods for emergency personal monitoring
Section H: Dose assessment methodologies and software
Section I: Recommendations on medical management
Section J: Public information and communication
Section K: Emergency exercises
Section L: Research and development projects
Finally, Section M asks the responder to provide any other information that they consider relevant.

The network currently has 51 individual members from 22 EU countries, 8 non-EU countries and two international organisations. Questionnaires were sent to all 51 EUREMON members. Three E-mails did not reach destination, two responders were unable to help, 19 questionnaires were returned and 27 members did not reply at all. This is a slight under-estimate of the true return rate because in some instances questionnaires were sent to more than one person within an organisation in a particular country whereas a single questionnaire was returned for that organisation, e.g. STUK (Finland), GAEC (Greece) and NRPA (Norway).

Compilation of information on portable and transportable monitoring facilities

Information has also been collected on portable and transportable monitoring facilities and equipment that could be used for individual monitoring in the event of an accidental or deliberate release of radioactive material resulting in internal or external contamination. Here “portable” means equipment that can be carried and operated by hand by an individual or a small team, while “transportable” means equipment that must be transported by a vehicle (e.g. a car, truck, train or aircraft). The aim is to compile information that can be madefreely available to national authorities who may require assistance in carrying out individual monitoring of members of the public in the event of an emergency.

To date, information has been compiled in the form of short reports for four EU countries: Finland, France, Spain and the United Kingdom. These reports are appended to this report in Appendices E, F, G and H. Other EUREMON members will be invited to contribute similar reports. The compilation will then be published in the open scientific literature.

Conclusions

A network of people with direct responsibility for monitoring and dosimetry of people in the event of a radiological emergency has been established. The following possible issues that would promote emergency preparedness in the field of individual monitoring and dose assessment were identified:

- The need for national surveys of inventories of available equipment suitable for emergency personal monitoring
- The development of desktop emergency exercises as a training tool for EUREMON members, focussed on monitoring, dose assessment, and management of members of the public
- The need for guidance on rapid in vitro analysis methods
- The need for dose assessment software appropriate for exposures received by members of the public, including assessment of absorbed doses received over short periods
- The need for guidance on the use of Prussian Blue for enhancing the clearance of radiocaesium, aimed at limiting exposures of members of the public.
- The promotion of cooperation and sharing of resources (e.g. bioassay laboratories) between EU countries

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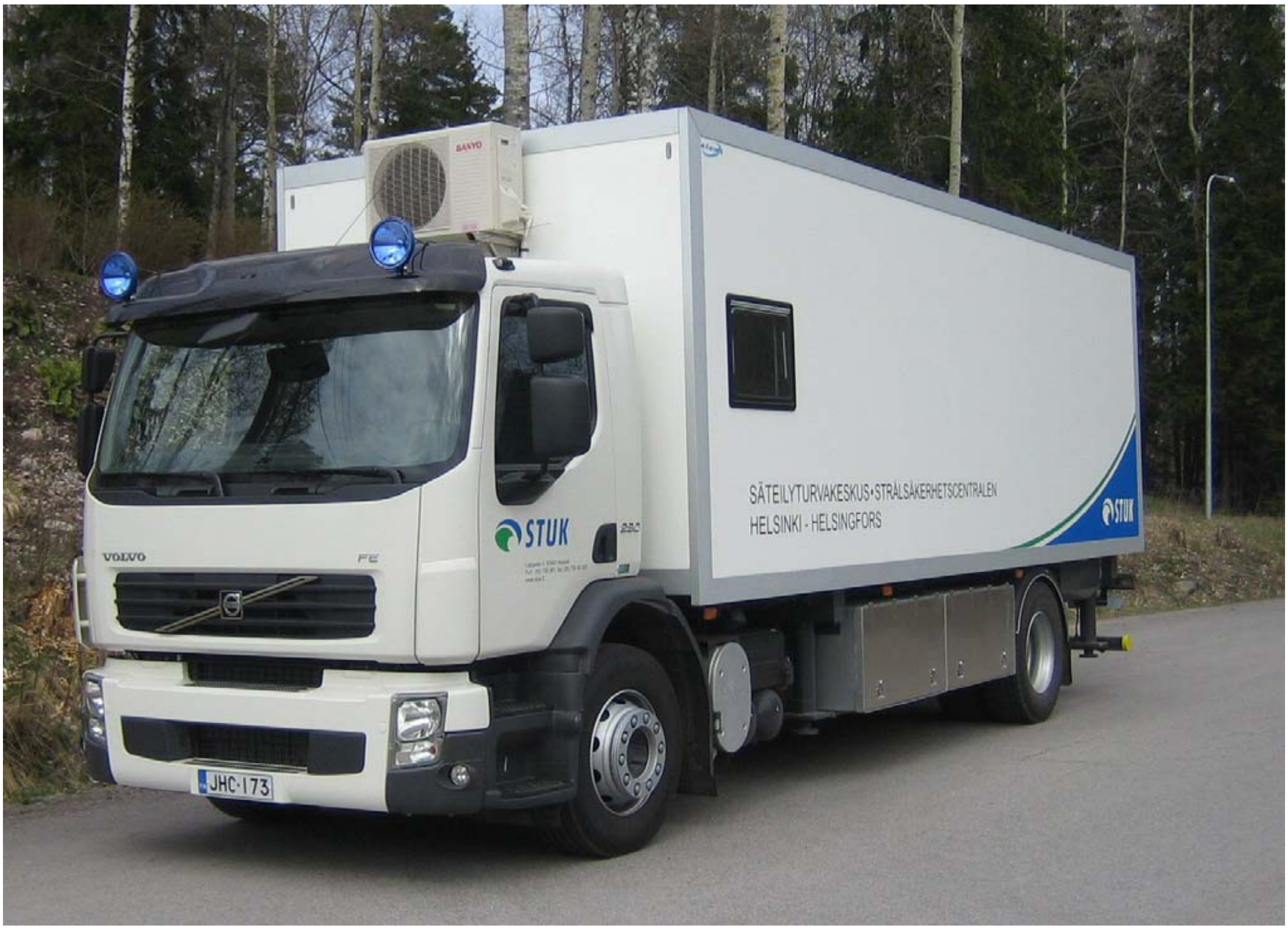

Figure 1.STUK’s new vehicle for whole-body counting

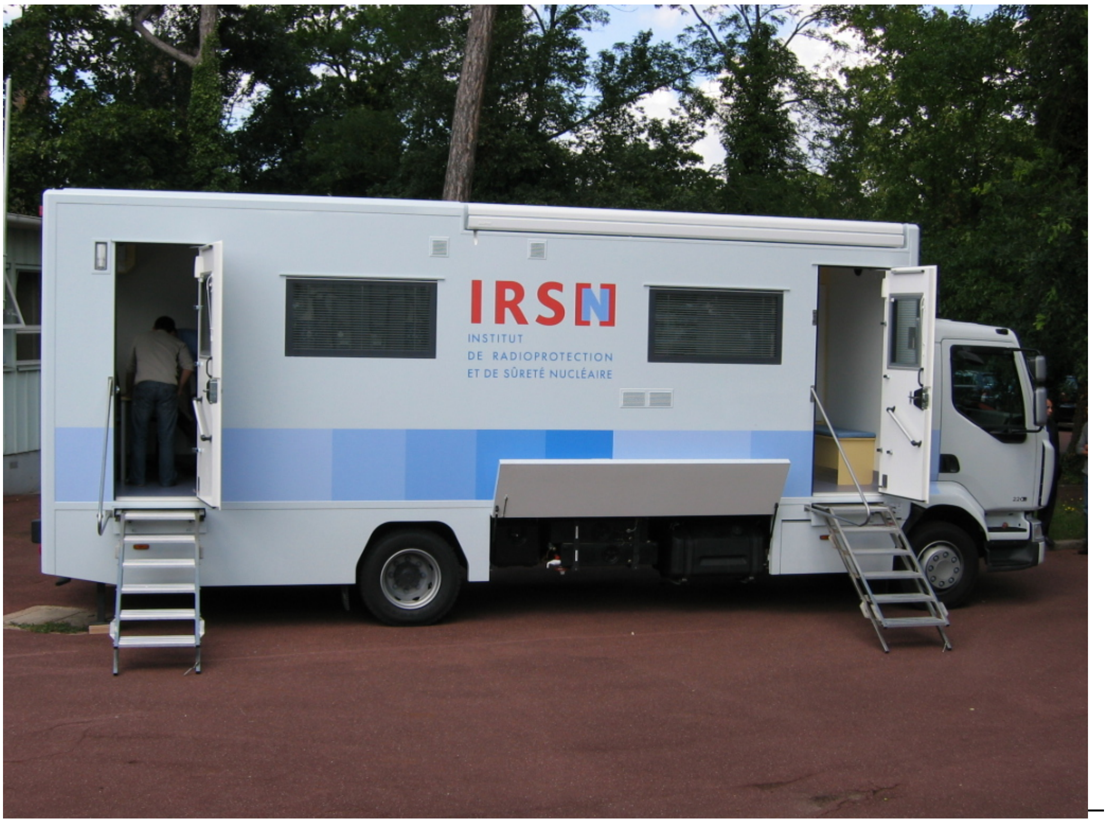

Figure 2. IRSN new mobile vehicle for body counting

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A European network for experts with direct responsibility for monitoring and dosimetry after a deliberate release of radioactive material or a deliberate radiation exposure

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Abstract

In the event of an accidental or deliberate release of radionuclides to the environment, individual monitoring and dose assessment may be needed for large numbers of people. The consequences of such incidents are not limited by national boundaries. However, within the European Union (EU), there has not been any coordinated strategy for individual monitoring and dose assessment. CONRAD (**CO**-ordinatio**N** Action for **RA**diation **D**osimetry) is an EC 6th Framework Programme Co-ordination Action sponsored by EURADOS (the European Radiation Dosimetry Group, http://www.eurados.org). The objective of Task 5.4 of Work Package 5 of the CONRAD project, coordinated by HPA (UK) and STUK (Finland), is the development of a network of people and organisations with responsibilities for emergency monitoring of emergency services personnel and members of the public.

The network (named EUREMON) aims to promote sharing of information between countries on plans and arrangements for individual monitoring. It currently has 51 individual members from 22 EU countries, 8 non-EU countries and two international organisations. After it was established, the network was used in a survey of plans and arrangements for emergency personal monitoring in EU countries. A report on the results of the survey is currently in preparation. Information is also being compiled on portable and transportable monitoring facilities and equipment in the EU.

KEYWORDS: emergency monitoring network; individual monitoring; deliberate releases of radionuclide; dose assessment; internal radiation exposure

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